THE ELECTRIC TELEPHONE

Edwin James Houston, Arthur Edwin Kennelly

ELEMENTARY ELECTRO-TECHNICAL SERIES

THE ELECTRIC TELEPHONE

BY

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PREFACE.

When it is remembered that the first public exhibition of the articulating telephone in the United States was made in 1876, at the Centennial Exhibition in Philadelphia, and that to-day there are in the United States about 750,000 telephones in use, by means of which, in the central exchanges alone, more than two millions of telephonic communications are effected daily, it is evident that the growth of this art has been unprecedented in the annals of applied science. This rapid growth, which has occurred in but two decades, has rendered it difficult for the general public either to follow the improvements which have rapidly succeeded

each other, or even to become familiar with the fundamental principles of the art.

The authors have prepared this little book on the telephone, in the hope of enabling those who are not trained in electro-technics to understand the main principles and method of operation of the telephone systems of to-day.

The authors desire to acknowledge their indebtedness to Mr. Arthur Vaughan Abbott's valuable series of articles in *Electrical Engineering*, and Mr. Herbert Laws Webb's *Telephone Hand Book*.

PHILADELPHIA, *October*, 1896.

Since this preface was written much growth and development have taken place in telephonic engineering and practice. The authors have, however, added three new chapters upon the subjects of principal recent importance, and believe, that by so doing, the book will be brought up to date.

PHILADELPHIA, *December*, 1901.

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THE ELECTRIC TELEPHONE.

CHAPTER I.

INTRODUCTORY.

THE time has long since passed when the world's wonders were but seven in number. To-day they are far more numerous, and science is constantly increasing their number. To the unreflecting mind, a wonder necessarily ceases to be regarded as such as soon as its use becomes a part of the daily life of the community, but it must be acknowledged that in reality a wonder may increase rather than decrease as its use is multiplied. What can be more marvellous than a

photograph, and yet, because so familiar, it has already ceased to be regarded as marvellous!

Though electric science has wrought many wonders, probably none can compare with the articulating telephone. The rapidity with which this instrument has become a part of our every-day life has caused it to assume the rôle of a necessity rather than that of a marvel. It can, indeed, be fairly regarded as one of the world's greatest modern wonders.

It is difficult to estimate the influence which the telephone has exerted upon our business and social life. Its advent has fairly revolutionized business methods. It was said of the invention of logarithms that their use doubled the effective work of the astronomer. It can be said to-

day of the telephone that it more than doubles the effective work of the business man. It gives him a capability of ubiquity so far as all points in telephonic connection are concerned; for, can he not, with the rapidity of light, along the aerial or underground wires, enter, for all conversational purposes, the office of his correspondent, remain only as long as is necessary for conversation, and again return in the twinkling of an eye to his own office?

It is not our intention in this little book either to enter into the history of the telephone, or to attempt to assign to the various claimants of this invention the credit which is their due. It will suffice to state that the practical introduction of the articulating telephone into the United States was coincident with the Philadelphia

Exhibition of 1876. In other words, although but about two decades have passed since the telephone was exhibited publicly for the first time in the United States, yet, during this time, its growth in this country has been so rapid that about 750,000 telephones are in use to-day, through which about 750,000,000 conversations are made annually through the telephone exchanges.

Many years ago, an exceedingly complex piece of apparatus was devised, which was known as the talking machine. It consisted essentially of an acoustic apparatus, driven pneumatically, and provided with various pipes and contrivances for producing the elements of the various sounds required for articulate speech. By means of a key-board these different pieces of acoustic apparatus were brought into

successive action, so that, being properly operated, they roughly imitated the human voice and produced a semblance of articulate speech. Between this complex and clumsy contrivance and the articulating telephone of to-day there is indeed a great gulf.

A circular metallic diaphragm, supported at its edges and placed opposite to an electromagnet, not only replaces the mechanism of the talking machine, but does this in a far more efficient manner; for, at its best, the talking machine was limited to a comparatively narrow range of sounds, while the telephone of to-day is capable of producing the sounds of any language spoken into it. Moreover, the telephone can transmit articulate speech to great distances.

Long before the discovery of the articu-

lating telephone, the possibility of transmitting speech for short distances, by means of mechanical vibrations carried through elastic wires, was well known, but such instruments ought to be carefully distinguished from the electric telephone, as will be shown in a subsequent chapter. With the electric telephone, the distance to which articulate speech can be transmitted has already reached 1,500 miles, and there is no reason why this should be the limit.

CHAPTER II.

ELEMENTARY ACOUSTIC PRINCIPLES.

The word sound is used in two distinct senses; namely, objectively, as the cause of a sensation, and subjectively, as the sensation itself. Objectively, sound consists of to-and-fro motions or vibrations in a medium, usually the air, through which the sound is transmitted. When a piano string, for example, is struck, it swings to-and-fro with a rapidity depending upon its tension, or the force with which it is stretched, and its dimensions. The shorter and thinner the string, and the greater its tension, the more rapidly does it vibrate; that is, the more frequently does it move

to-and-fro in a given time. During these to-and-fro motions of the string, the surrounding air is set into oscillations which are transmitted outwards in all directions. At any point in the surrounding atmosphere, the air is alternately condensed and rarefied, that is to say, the oscillation causes a greater number of air particles or molecules to occupy a given space during one part of the movement, and a smaller number during the succeeding part of the movement. Each to-and-fro movement of the string, or to-and-fro movement of an air particle, is called a *complete vibration;* the time occupied by a complete vibration is called a *period;* and the number of complete vibrations, or to-and-fro movements, executed in one second of time is called the *frequency* of the vibration.

The almost infinite variety of sounds,

occurring objectively in nature, differ in only two respects; namely,

(1) In tone, pitch or frequency.

(2) In loudness or intensity.

If we successively strike the separate strings on a piano, we will obtain the well-known succession of musical notes or tones. Moreover, by striking them with different degrees of force, we may obtain these notes either as faint, weak sounds, or as strong, forcible sounds. These different notes are said to differ from one another in *pitch*, that is, some are higher, or shriller, and some are lower, or graver. Or, they may differ in their *loudness* or *intensity*.

If we strike a note on the piano, and then sound the same note by the voice, or produce it on a violin, a difference will be recognized in the effect it produces,

subjectively, on the mind through the ear; for, even though these sounds be in unison, and be sounded with equal intensity, yet a characteristic difference is apparent between them.

The reason for the above characteristic difference is found in the fact that the so-called simple sounds consist, in reality, of an assemblage of numerous, separate tones or sounds of different pitch and markedly different loudness. What the ear generally recognizes as the pitch of such sounds, is, in reality, the pitch of only one of these tones, usually the gravest and loudest, called the *fundamental*. The additional sounds or the *overtones*, or, as they are sometimes called, the *harmonics*, mingle with the fundamental tone, and give it that characteristic which is called its *timbre* or *quality*.

A note sounded on the piano differs from the same note sounded on the violin, in the fact that although the fundamentals of the two notes may be practically the same, yet the over-tones differ both in their number and in their relative intensities. It is evident, therefore, that while there are objectively but two characteristics of sounds, there are subjectively three; namely,

(1) Tone or pitch.
(2) Loudness or intensity.
(3) Quality or timbre.

It follows from the preceding that if all musical instruments gave simple tones, they could not be distinguished from one another except in loudness. The nearest approach to a simple tone is that emitted by a properly constructed and sounded tuning fork mounted on its resonant case. It

is in this sense that the notes of some instruments are properly described as brilliant and those of others as dull; for, each of the tones so produced being in reality chords consisting of a fundamental and a number of harmonics, the effects produced vary with the number and degree of prominence of the harmonics.

When the string of a piano moves to-and-fro, after being struck, it produces a musical sound which is transmitted through the air by a succession of waves. Regarding the moving string as producing its to-and-fro motions in a direction towards and from an observer, when the string is moving towards him it crowds together or condenses the air in front of it, moving it in straight lines towards the ear. The particles, however, do not continue to move forward through the entire distance between

the string and the observer's ear, but give up their motion to neighboring particles in front of them, and then move back towards their original position. Meanwhile, the particles set moving onwards communicate their motion to those next in the same line.

The original motion is thus transmitted onward from particle to particle with a definite velocity depending on the elasticity and density of the medium. In air this velocity is 1,090 feet per second at 32° F., or 332.2 metres per second at 0° C. In this manner the air between the string and the observer's ear is set in vibration in paths which are in the direction in which the sound is travelling. Such vibrations are called *longitudinal vibrations*, in order to distinguish them from *transverse vibrations*, which take place

across the line of transmission, as in the vibrations constituting light.

If the vibrating string be moved to one side and then stopped, the blow or impulse given to the air would move forward as a wave, at a velocity of about 1,090 feet per second, in air at the temperature of freezing water. Each particle of air would make one excursion forward and then return to its original position, when it would remain at rest. If, however, as is always the case, the string repeats its pulses successively forward and backward, at regular intervals, motions are set up in the air particles, each pulse moving forward at the same velocity. If, for example, the string has a frequency of vibration of unity, or makes one *period*, or *double-vibration*, or to-and-fro motion per second, then the first pulse through

the air is followed at each second of time by another pulse, the corresponding portions of the pulses being, therefore, separated by 1,090 feet in space. This distance is known technically as the *wave length.* At points along the direction of transmission, the moving air particles at this distance apart have the same direction and relative velocity of motion. If the string makes two complete vibrations per second, or has a frequency of 2, there will be two pulses during the time that the motion is transmitted through 1,090 feet, or each wave will be 545 feet long. In the same way, if the frequency of the string be 1,090, so that it executes 1,090 to-and-fro motions per second, corresponding, approximately, to the note C″♯, each impulse can only move through a distance of 1 foot, before the next impulse follows it, so that the wave length will be 1 foot. Generally,

the wave length of a sound is its velocity of transmission, divided by the frequency.

Let us now examine the consequences of striking the string more forcibly at one time than at another. The tension of the string and its dimensions remaining the same, no sensible effect is produced upon its frequency; consequently, the wave length will remain the same, and the string will give the same tone, but the excursions of the string and also of the air particles will be increased, so that the *amplitude* of the wave; *i. e.*, the amplitude of the excursion of each particle is increased. For the same reason the actual velocity of each particle is also increased. The velocity of the particles is to be carefully distinguished from the constant velocity with which the wave travels or moves forward, or the velocity of trans-

mission. It is evident that each particle has alternately a maximum onward and backward motion, and that when it reaches the extremity of each excursion and is ready to change its direction, it comes to momentary rest while the wave continues to advance steadily.

It is evident from the preceding that the transmission of sound to the observer's ear necessitates first the presence of a vibrating body, and second that of an elastic medium connecting the vibrating body with the observer. It remains now to briefly explain the manner in which the air impulses or vibrations act upon the ear of the observer.

Without attempting to enter into a description of the anatomy of the ear, it suffices to say that this delicate organ of

hearing consists essentially of means whereby the sound waves entering the ear impinge against a tightly stretched membrane called the *tympanic membrane.* The to-and-fro motions of this membrane are transmitted, by means of a chain of bones, to another membrane that closes an internal cavity filled with liquid and containing ramifications of the auditory nerve. The manner in which sounds of different pitch produce their characteristic impressions on the observer, due to the difference in their frequencies, is substantially by means of the vibrations they excite in a series of minute rods or fibres. These rods or fibres vibrate, apparently at definite frequencies, and are only excited by waves of their own frequency. The ear is thus enabled to analyze a complex sound and resolve it into its component tones.

So sensitive is the human ear, that the amplitude of the vibration of the air particles capable of exciting the sensation of sound, has been found experimentally to be less than $\frac{3}{100,000,000}$ths of an inch, representing a maximum velocity of $\frac{1}{20,000}$th inch-per-second in each air particle transmitting the wave, for the tone of middle C, or C′ of the pianoforte.

It is the short, thin strings on musical instruments, such as the piano, which have a comparatively high frequency or produce a comparatively great number of vibrations per second, while it is the long, thick strings that vibrate slowly and produce the grave tones. The human ear is capable of distinguishing frequencies ranging from 16 to about 40,000 periods

or double vibrations per second. The extreme range of the human voice, including male and female, is from 43 periods per second to about 3,000 periods per second. This range is, approximately, 6 octaves, 2 octaves being the average range of the adult voice, and 4 1/2 octaves being the greatest known range of a single voice. In ordinary conversation the range of tones is much smaller, 300 periods per second being about the average frequency.

The brief description we have given of the elementary principles of sound find an excellent illustration in the simple string telephone. As has already been stated this form of telephone does not involve any electrical principles in its operation, a series of mechanical waves, instead of electrical waves, being transmitted between the two instruments. A form of string

telephone is diagrammatically shown in Fig. 1. It consists essentially of two open cylinders *A* and *B*, provided with diaphragms *D*, D_1, formed of stiff paper, or other suitable material, and connected by an elastic string or thread *s*, s_1, secured

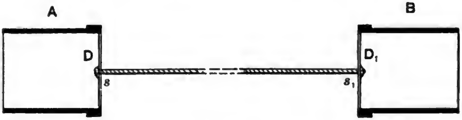

FIG. 1.—STRING TELEPHONE.

to the centres of the diaphragms. A person talking into the open end of one of these cylinders, as at *A*, can be distinctly heard by a person listening at the open end of the other cylinder *B*, even when the cylinders are separated by a distance of many feet. The instrument into which the speaker talks is sometimes called the *transmitting instrument*, or *transmitter*, and

that into which his interlocutor listens, is called the *receiving instrument*, or *receiver*. In this case each instrument can be used alternately either as a transmitter or as a receiver.

We will now explain the manner in which articulate speech is transmitted by mechanical waves from the transmitter to the receiver, and how it is able, at the receiver, to reproduce on the listener's ear whatever is spoken into the transmitter.

The effect of the sound waves produced by the speaker's voice impinging on the diaphragm of the transmitter *A*, Fig. 1, is to set the diaphragm into vibration with a frequency and amplitude corresponding to the frequency and amplitude of the sound waves. These vibrations of the diaphragm, being communicated to the end

of the string, produce in it longitudinal pulses of corresponding amplitude and frequency, which travel along the string and impart to the diaphragm of the receiving instrument similar vibrations.

Consequently, the air in the receiver *B*, is set in vibrations of the same character as those produced by the voice at *A*. A person standing alongside the speaker at *A*, could hear this speech on account of the direct communication of these vibrations to the surrounding air. So a listener, with his ear opposite *B*, will be able to hear the same speech reproduced through the to-and-fro motions of the diaphragm *D*, transmitted along the string.

We shall subsequently show that the electromagnetic telephone differs in no respect from the mechanical telephone so

far as the action of the sound waves on the diaphragm of the transmitting instrument is concerned, or the reproduction of similar sound waves in the air of the

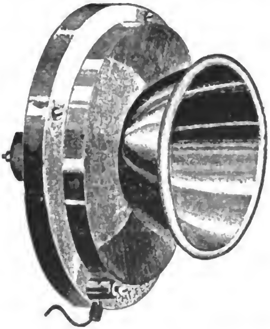

FIG. 2.—MECHANICAL TELEPHONE.

receiver. A radical difference, however, is found in the fact that in the string telephone actual sound waves or longitudinal pulses are transmitted along the string connecting the two instruments, while in

the electromagnetic telephone a series of electric pulses or waves, of a frequency and amplitude dependent on the frequency of the tones of the speaker's voice, are transmitted along the wire connecting the two telephones, and are capable of reproducing similar motions in the diaphragm of the receiving instrument, and, consequently, the speech at the transmitting instrument. A form of mechanical telephone, operating in general in the same manner as the simple telephone of Fig. 1, is shown in Fig. 2.

CHAPTER III.

ELEMENTARY ELECTRICAL PRINCIPLES.

Before attempting a detailed description of the method of operation of the electric telephone, it will be necessary to obtain a clear conception of some of the elementary electric principles involved. Since electric energy is but one phase of energy, and since we are never able to create energy, but can only transform or change it from one phase to another, it is evident that all electric energy requires the expenditure of some other form of energy for its production. Thus mechanical, chemical, thermal or luminous energy may be converted into electric energy. Any means by which this transformation

is effected is called an *electric source.* All electric sources have two points, called *poles,* one the *positive pole,* where an electric current is assumed to pass out, and the other the *negative pole,* where it again re-enters it, after having completed a passage through a conducting line or *circuit.*

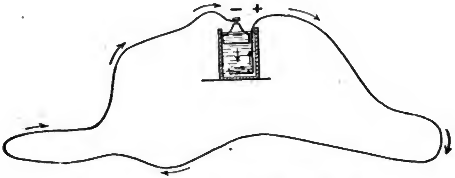

FIG. 3.—SIMPLE ELECTRIC CIRCUIT.

A great variety of electric sources exist. Some of the commonest of these are the dynamo-electric machine, the frictional electric machine, and the voltaic cell. A simple electric circuit is shown in Fig. 3, consisting of a voltaic cell and a conduct-

ing wire. The poles of the source or voltaic cell are shown at (+) and (−), which are called respectively the positive and negative poles. It is assumed for convenience that electricity flows out of the cell at its positive pole, and returns to it at its negative pole, completing its path by passing through the cell. The complete path thus provided is called the circuit.

Although electric sources are popularly said to produce electricity, yet, in point of fact, they are more correctly described as being means or devices for the transformation of some form of energy into electric energy. In the case of the voltaic cell described in connection with Fig. 3, two dissimilar metals called the *voltaic elements* are dipped in a solution called the *electrolyte*. The electric energy supplied by the cell is obtained at the expense of

the chemical energy existing in the elements and electrolyte.

No electric sources produce electricity directly. What they directly produce is a variety of electric force called *electromotive force*, usually abbreviated E. M. F., and this E. M. F. is always developed as long as the electric source remains active. But the E. M. F. will be unable to produce an electric current unless a path or conducting circuit is provided for its passage; thus, if we break or cut the wire in Fig. 3, thus opening or breaking the circuit, the E. M. F. of the voltaic cell will still be present, but there will no longer be a passage of any electric current under the action of this E. M. F. E. M. F. may be defined, therefore, as the force which sets, or tends to set, electricity in motion; that is, produces an electric current. No

current can flow without the action of an E. M. F.

E. M. F. is measured in terms of a *unit of E. M. F.* called the *volt.* An ordinary bluestone Daniell cell has an E. M. F. of, approximately, 1 volt, (1.08) and a Leclanché cell, a form of cell commonly employed in telephony, has an E. M. F. of, approximately, 1 1/2 volts. A *storage cell* or *secondary cell* has an E. M. F., when in action, of about 2 volts. Dynamo-electric generators may be built so as to produce any desired E. M. F. from a small fraction of a volt to many thousands of volts. Frictional electric machines generate E. M. Fs. of hundreds of thousands of volts. The E. M. F. which produces lightning may be many millions of volts.

When an E. M. F. acts upon a circuit,

the amount of electric current it produces will depend not only upon the magnitude of the E. M. F., but also upon the opposition which the circuit offers to the flow; or, as it is termed, on the *electric resistance* of the circuit.

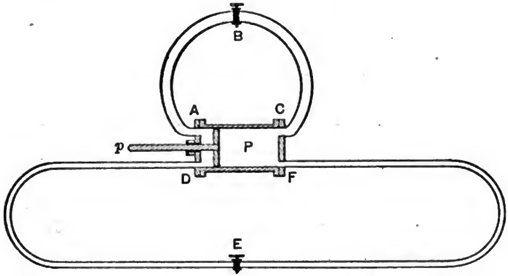

FIG. 4.—HYDRAULIC CIRCUITS IN PARALLEL.

An analogue of this condition is shown in the *hydraulic circuit*, illustrated in Fig. 4. Here a cylinder P, filled with water, is provided with a piston p, capable of moving to-and-fro. Two pipes connect

the front and back end of the cylinder, one *A B C*, being a short, wide pipe, and the other *D E F*, a long, narrow pipe. Under these conditions, if the system be filled with water and the piston be set in motion, a current of water will be caused to circulate through both pipes, but the flow through the long pipe will be much less than through the short pipe.

Here clearly, that which causes the water to flow through the pipes is the *pressure* or *watermotive force* created by the action of the pump between the two ends of each pipe. But the resistance of the long pipe to the flow of water is much greater that the resistance of the short pipe. Consequently, the flow which is established by the head or pressure is much smaller in the long pipe than in the short pipe.

Comparing the hydraulic circuit with the electric circuit, as shown in Fig. 5, we find that in the short, thick wire circuit *A B C*, the current strength which is established under the influence of the E. M.

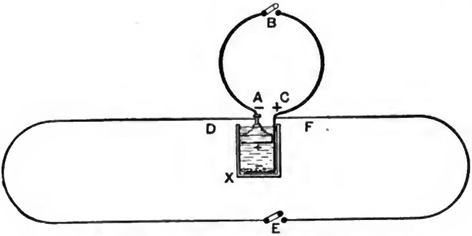

FIG. 5.—ELECTRIC CIRCUITS IN PARALLEL.

F. or *electric pressure*, produced by the voltaic cell *X*, is much greater than in the long, thin wire *D E F*, because the electric resistance of the former is much less than that of the latter.

The resistance which a water-pipe offers to the flow of water through it, depends

upon the character of its walls, whether smooth or rough, upon the length of the pipe, and upon the area of its cross-section. The resistance which an electric conductor offers to the flow of electricity through it, depends upon the character of the conductor; *i. e.*, the nature of the material, its temperature, physical condition and purity, and also upon its length and area of cross-section. The longer a wire, the greater its resistance; the smaller its cross-section, the greater its resistance. If, therefore, we double the length of a wire, we double its resistance, and if we double its cross-section, the length remaining the same, we halve its resistance. Consequently, if we double both the length and cross-section, the resistance of the wire will remain unchanged.

Electric resistance is measured in terms

of a *unit of resistance* called the *ohm.* This unit has been defined as being equal to the resistance offered by a column of mercury 106.3 centimetres in length and 1 square millimetre in cross-sectional area at the temperature of melting ice. A wire of soft copper, 1 foot in length, and of No. 40 A. W. G., or of 0.003145″ diameter, has a resistance at 45° F., of 1 ohm, while 2 miles of ordinary trolley wire, such as is used on our cities' overhead trolley lines, has a resistance of about 1 ohm. The resistance of an ordinary telephone receiver is about 75 ohms. The resistance of 1 mile of No. 12 A. W. G. (0.0808″ diameter) copper wire, is about 8.37 ohms. This is a size of wire commonly used in telephony.

The resistance of common soft copper wire, of standard purity, may be found by

taking the resistance of a *mil-foot* at the required temperature, say 68° F., (10.355 ohms), multiplying by the length of the wire and dividing by the cross-sectional area in *circular mils* (obtained by squaring the diameter of the wire expressed in *mils* or thousandths of an inch). Thus a mile of No. 12 copper wire, whose diameter is 80.8 mils, (0.0808″) will be $\frac{5,280 \times 10.355}{80.8 \times 80.8}$ = 8.376 ohms at 68° F.

The resistance of an electric circuit is the sum of the separate resistances of its parts. Thus in Fig. 6, are shown two ordinary telephones *A* and *B*, connected together by a pair of No. 12 copper wires, each 1 mile long. The resistance of each telephone being, say 75 ohms, their total resistance will be 150 ohms; the resistance of 1 mile of this wire at 68° F. being 8.38

ohms, 2 miles will have 16.76 ohms; so that the total resistance of the circuit will be 166.76 ohms.

We have already stated that the resistance of a conductor depends not only upon its dimensions, but also upon the nature of the material. Thus copper and silver are the best known conductors, so that wires of copper and silver have the lowest resistance for any given length and cross-section. An iron wire has about 6 1/2 times the resistance of a copper wire of the same dimensions; a lead wire, about 12 times, and an aluminum wire, twice, the resistance of a corresponding size of copper wire.

In order to compare the resistances of wires of different substances, but having the same size and length, it is usual to consider the resistance offered by a unit length

of the wire having unit cross-section. This resistance is called the *specific resistance* or *resistivity* of the wire. The length adopted is the centimetre, and the cross-section the square centimetre, so that the statement of the resistivity of standard copper as 1,594 microhms at 0°C. or 32° F., means that a wire of this copper, 1 centimetre long and 1 square centimetre in cross-sectional area, would have a resistance at this temperature of $\frac{1,594}{1,000,000}$ths of an ohm. Consequently, the resistance of a wire of given length and cross-section can be readily computed, when either its resistivity at the observed temperature is known, or when the resistance of a mil-foot of the wire is known.

The class of substances called *insulators*, such as glass, hard rubber, silk, wool, vul-

canite, etc., have enormous resistances as compared with metals. Thus, a rod of gutta percha 1 foot long and of the same diameter as No. 7 A. W. G. (0.1443″) would have a resistance of about 200 quadrillions of ohms at ordinary temperatures, assuming no surface leakage.

The electric flow or current in a circuit is measured in terms of a *unit of electric current* called the *ampere*, after the physicist of that name. The current strength which passes through an ordinary 16 candle-power incandescent lamp is usually about half an ampere, when operated on a 110-volt circuit. The current strength supplied to an arc lamp is usually about 10 amperes. The current strength employed in telephony is extremely small, so small that it is very difficult to measure, and is usually estimated in fractions of an

ampere called a *micro-ampere*, a micro-ampere being only the $\frac{1}{1,000,000}$th of an ampere. The estimated current strength employed in telephonic circuits is from 5 to 100 micro-amperes. A telephone will, however, respond audibly to a current strength of 44 *bicro-amperes*, one bicro-ampere being the billionth part of an ampere. Consequently, one 16 candle-power incandescent lamp receives a current strength sufficient to actuate audibly about ten million telephones.

The current strength which flows in a circuit depends both on the electric pressure or E. M. F. and on the resistance of the circuit. The greater the E. M. F., the greater the current strength, and the greater the resistance, the less the current strength. It was first shown by Dr. Ohm

of Berlin, that the current strength in amperes in any circuit was equal to the quotient of the number of volts of E. M. F. in the circuit divided by the total resistance of the circuit in ohms, or Ohm's law may be expressed

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}.$$

Thus, if the circuit shown in Fig. 6 included an E. M. F. of 1 volt, the current strength which would flow under this pressure would be $\frac{1 \text{ volt}}{166.76 \text{ ohms}} = 0.005997$ ampere. This would represent 5,997 microamperes, or 5.997 *milliamperes*, the milliampere being the $\frac{1}{1000}$th part of an ampere. Again, if a dynamo-electric generator produces at its terminals a pressure of 100 volts, and the resistance of an incandescent lamp, when hot, is 200 ohms,

the current strength which would flow through the lamp, when the latter is directly connected with the dynamo terminals, is $\frac{100 \text{ volts}}{200 \text{ ohms}} = 1/2$ ampere.

A current which always flows in the same direction through a circuit is called a *continuous current*, or sometimes a *direct current*, and is produced by a *continuous E. M. F.* A current that alternately reverses its direction through a circuit, that is, flows first in one direction, then stops and flows in the opposite direction, then stops and flows again in the first direction, and so on, is called an *alternating current.* Alternating currents are commonly employed in electric lighting and in the distribution of power. They are invariably employed in telephony. It is, therefore, necessary to inquire into the

elementary principles of alternating currents in order to explain the operation of the articulating telephone.

Alternating currents are produced by the action of *alternating E. M. Fs.* An alternating E. M. F. is one which periodically reverses its direction. Fig. 4, represents the hydraulic analogue of an alternating current circuit and pressure; for, every reversal in the direction of the piston will produce a reversal in the direction both of the pressure and of the water flow. A chain pump, on the other hand, if substituted for the piston pump shown, would afford the corresponding analogy to a continuous E. M. F. and current.

The effect of producing sound waves in the neighborhood of one telephone as a transmitter, say *A*, in Fig. 6, is to produce,

in its diaphragm, vibrations which result in the production of alternating E. M. Fs. in the circuit. The frequency of these E. M. Fs. will be the same as the frequency of the vibrations of the diaphragm; and, therefore, of the sound waves producing them. For example, a single note of 512 double vibrations per second, corresponding to C'' in the musical scale, will, therefore, have a frequency of 512 cycles per second, and the period of this sound will be $\frac{1}{512}$th second, so that two reversals of the motion of an air particle will take place in this period of time. The diaphragm will vibrate with this frequency, and will produce an E. M. F. of 512 double alternations per second; that is to say, 512 pulses of E. M. F. in one direction, through the circuit, alternating with 512 pulses of E. M. F. in the opposite

direction. If the circuit be open, this alternating E. M. F. will be unable to send a current; but, if the circuit be closed, as shown in Fig. 6, an alternating current will flow, whose pulses have the same frequency as the E. M. F.

If a composite tone be sounded before a transmitting telephone, each simple tone of which it consists will produce its corresponding vibration in the diaphragm, and a corresponding series of alternating E. M. Fs. will be developed in the circuit, each having the frequency and following in amplitude the respective frequency and amplitude of the component tones. A telephone acting in this manner as a transmitter, is, in reality, a miniature alternating-current dynamo, driven by the power of the voice or sound vibrations in air. An ordinary alternating-current

dynamo, however, produces an E. M. F. which may be, and frequently is, several thousands of volts, while the telephone as an alternating-current dynamo only produces an E. M. F. of usually but a fraction of a volt. The frequency of the E. M. F. generated by an ordinary commercial alternating-current dynamo does

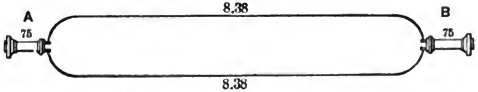

FIG. 6.—SIMPLE TELEPHONE CIRCUIT.

not vary in practice since it is fixed by the speed of its revolution. The frequency of E. M. F. generated by the telephone is constantly varying and depends upon the frequency of the tone or tones sounded in its vicinity.

When the alternating electric current produced by a sound at *A*, Fig. 6 and

which in practice always consists of an assemblage of different frequencies, passes through the coil of wire on the receiving telephone *B*, they produce vibrations in its diaphragm. The receiving telephone *B*, becomes, therefore, in a certain sense, an alternating-current motor, its diaphragm reproducing the vibrations which are set up in the diaphragm of the transmitter *A*, except that the vibrations of the receiver are feebler than the vibrations of the transmitter which produce them. The air in the neighborhood of the receiving diaphragm being set into corresponding vibrations, a listener at *B*, can recognize the sounds which are being produced in the vicinity of the transmitter *A*.

CHAPTER IV.

THE TELEPHONIC RECEIVER.

A MARKED peculiarity of the articulating telephone is its simplicity of construction, consisting, as it does, of only a permanent magnet, a magnetizing coil of insulated copper wire, and a soft iron diaphragm firmly secured at its edges in proximity to one of the magnet poles. Fig. 7, shows the form of telephone receiver generally employed in the United States, while Fig. 8, shows the essential parts of the instrument removed from the rubber case. *D*, is a diaphragm of soft ferrotype iron, 10 mils in thickness (0.010″). *C*, is a coil of silk-covered copper wire, whose diameter is 0.004″, or

4 mils. The resistance of the coil is about 75 ohms. *M*, is a permanent magnet, also

FIG. 7.—TELEPHONE RECEIVER.

represented in Fig. 9, formed of four bars of hard steel, separately magnetized, and then

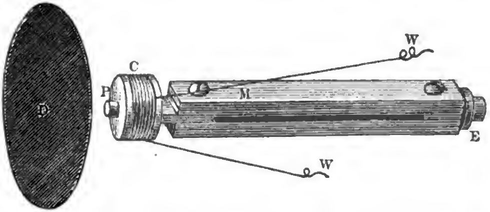

FIG. 8.—PERMANENT MAGNET, COIL AND DIAPHRAGM OF TELEPHONE.

clamped side by side. The magnetizing coil *C*, is wound upon a wooden spool

which slips over a soft iron projection securely fixed to one of the poles of the permanent magnet. The two ends *W*, *W*, of the magnetizing coil are led out to bind-

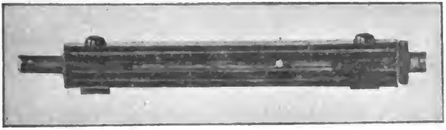

Fig. 9.—Compound Bar Magnet of Telephone Receiver.

ing posts *B*, *B*, Fig. 7, at the end of the instrument. The end of the compound magnet *E*, furthest from the coil, is provided with a projection threaded for the reception of a screw passed through the end of the cover. The object of this screw is to adjust the distance between the polar extremity *P*, and the diaphragm *D*, when the instrument is assembled.

A longitudinal section through the axis of this telephone is shown in Fig. 10. Fig.

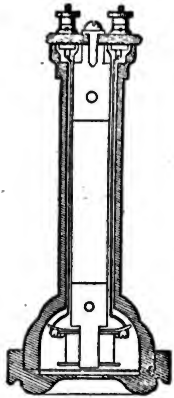

FIG. 10.—SINGLE-POLE RECEIVER.

11, shows the details of the mouthpiece and hard rubber case upon which the diaphragm is clamped.

Before inquiring as to the manner in which the electric currents sent over the line operate the receiving instrument, it will be necessary to examine into some of the elementary principles of magnetism;

FIG. 11.—HARD RUBBER CASE OF TELEPHONE.

for, it is by means of the magnetic force that the electric currents are enabled to reproduce in the diaphragm of the receiver the movements of the diaphragm of the transmitter.

It is well known that a permanent magnet possesses the property of attracting, and holding to its poles, pieces of soft iron

in its neighborhood, and also of attracting or repelling the poles of other permanent magnets in its vicinity. These phenomena are generally accounted for on the assumption that *magnetic flux*, or *magnetic streamings*, proceed from the poles of the magnet, and that it is these streamings which connect the magnet with the body on which it acts. The magnetic flux is assumed to pass out of the magnet at its north-seeking pole, to spread through the space surrounding the magnet, and to re-enter it at its south-seeking pole, completing what is called the *magnetic circuit*, by passing through the body of the magnet. Various shapes are given to permanent magnets, the simplest being the ordinary bar or rod. Such a magnet, called a *bar magnet*, is shown in Fig. 12. Were such a magnet supported at its centre by a string, so as to be free to

move, it would come to rest, approximately, in the north and south line, provided, of course, that it was not near a mass of iron, an electric current, or another magnet.

FIG. 12.—BAR MAGNET.

That end of the bar which points, approximately, to the north pole of the earth is called its *north-seeking*, or *north magnetic pole*, while the other end is called its *south-seeking*, or *south magnetic pole*.

If the bar magnet shown in Fig. 12, be uniformly sprinkled with iron filings,

the filings will not collect uniformly on the bar. There will be comparatively few filings near the middle of the bar, the bar possessing the appearance shown in Fig.

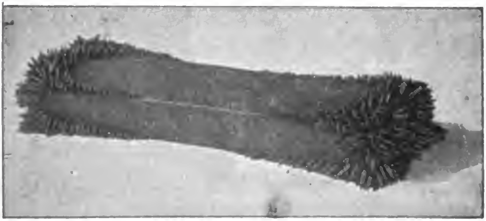

FIG. 13.—IRON FILINGS OVER SURFACE OF BAR MAGNET.

13, where the greater masses have collected near the ends or poles.

When iron filings are brought into the neighborhood of a magnet they become magnetized, and are thereby attracted to the poles of the magnet to which they cling. In order to study the direction in

which iron filings will arrange themselves in any single plane in the neighborhood of a magnet, a sheet of paper or glass may be

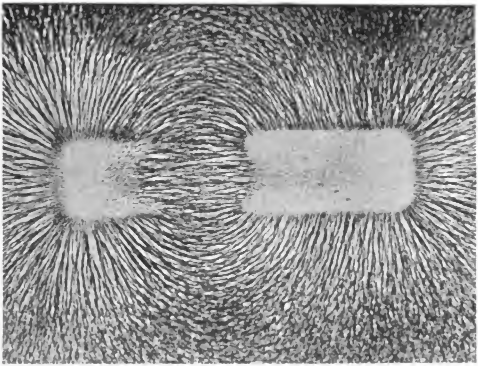

FIG. 14.—FLUX DISTRIBUTION OF STRAIGHT BAR MAGNET.

held directly over the magnet and iron filings sprinkled over its surface. On gently tapping the plate, the filings, in-

stead of being uniformly distributed over the surface, become arranged in definite

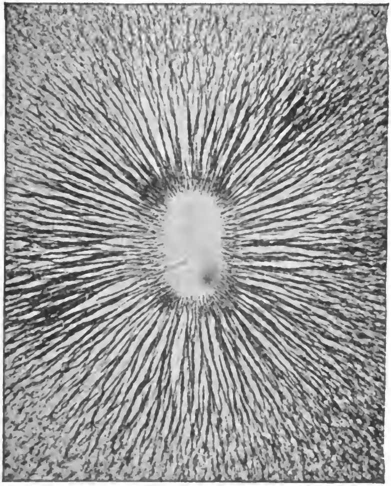

FIG. 15.—FIELD OF END OF BAR MAGNET.

paths or curved lines. Fig. 14, shows the appearance presented by the filings if the

glass plate be laid flat upon the bar, and Fig. 15, the corresponding appearance if the plate be laid perpendicularly over one of the poles.

An inspection of the preceding figures will show that the iron filings appear to be strung on invisible lines or threads joining the poles of the magnet. It is convenient to regard these lines as some of the actual paths through which magnetic flux travels.

Fig. 16, represents diagrammatically the arrangement of magnetic flux paths which are assumed to traverse the magnetic circuit of the bar shown in Figs. 11 and 12. A few only of the possible paths are indicated. These are assumed to leave the magnet at its north pole, to traverse the surrounding space, and to re-enter the magnet at its south pole, completing their

course through the substance of the magnet itself. A small compass needle will align itself on these curves in the direction

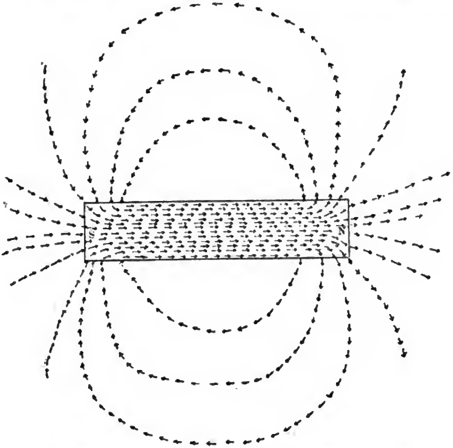

FIG. 16.—DIAGRAM OF MAGNETIC FLUX PATHS.

of the magnetic flux at the point it occupies, so that the flux of the magnet will pass through it in the same direction as

its own flux. A small compass needle, held in various positions in the vicinity of an ordinary telephone, will indicate the direction of the flux paths surrounding the magnet.

Fig. 17, represents the flux paths of an ordinary telephone magnet obtained by scattering iron filings over a sheet of glass supported horizontally over the magnet. *N* and *S*, represent the north and south poles respectively. The collections at *a*, *a*, mark the position of screw heads above the surface.

Fig. 18, represents the flux paths from the same magnet when either pole is presented vertically to the plate. Fig. 19 represents the flux paths of the same magnet after the diaphragm has been brought into position. Here the diaphragm occu-

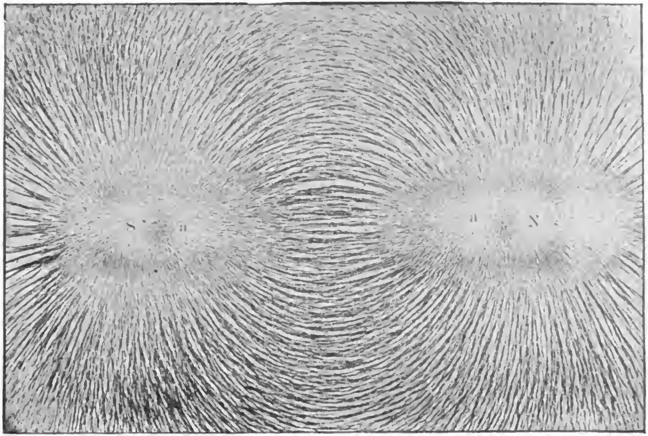

FIG. 17.—FLUX DISTRIBUTION OF BELL TELEPHONE MAGNET.

pies the position *d d*. It will be seen that the flux is intensified immediately in front of the pole *N*, but weakened in the spaces

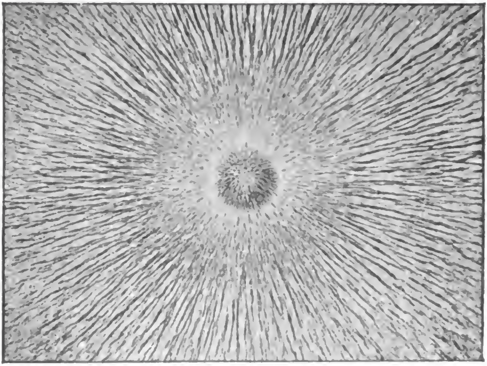

FIG. 18.—FLUX DISTRIBUTION OF BELL TELEPHONE MAGNET.

b, b. In other words, flux which in Fig. 17, leaves the pole *N*, through the regions *b, b*, Fig. 19, is now collected in front of the pole *N*, and passes through the diaphragm,

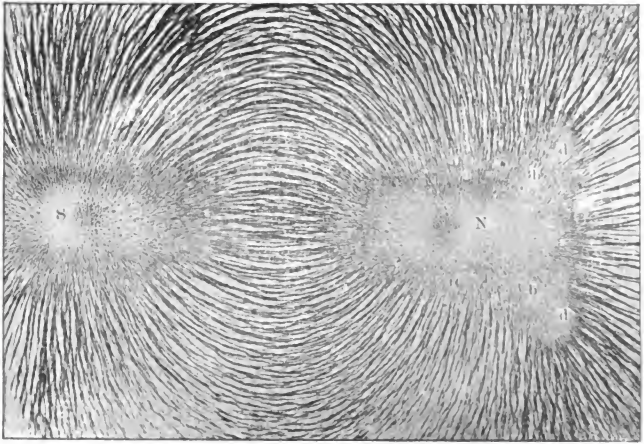

Fig. 19.—Flux Paths of Telephone Magnet with Diaphragm in Position.

the core of the telephone, and the coil placed thereon. The effect of the magnetic flux from the permanent magnet passing through the diaphragm in front of its pole is to attact the diaphragm and bend it inwards toward the pole. It is a matter of no consequence which pole of the magnet is presented to the diaphragm, provided that the diaphragm is of soft iron. This steady pull upon the diaphragm lasts as long as the telephone remains disconnected from its circuit.

There are two kinds of magnets; viz., *permanent magnets* and *electromagnets*. The former, as the name indicates, are permanent, and are made of hardened steel; the latter are made of soft iron, and their magnetic power is but temporary.

An electromagnet consists essentially

of a *core*, or bar of soft iron, encircled by a coil of insulated wire. Fig. 20 shows a simple form of electromagnet. *A B*, is a

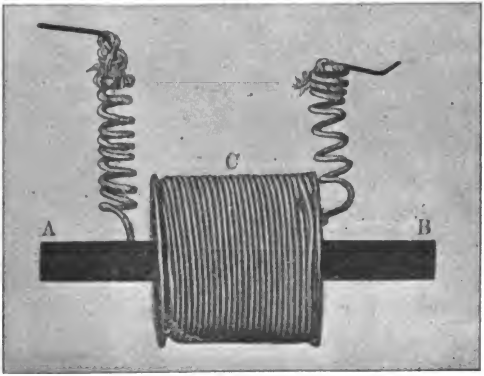

FIG. 20.—BAR ELECTROMAGNET.

bar of soft iron surrounded by a coil *C*, of insulated wire. When no current is passing through this coil, the bar remains in a neutral, or unmagnetized condition. If an

electric current be passed through the coil in one direction, the extremity at *A*, will become, say, a north pole, and the extrem-

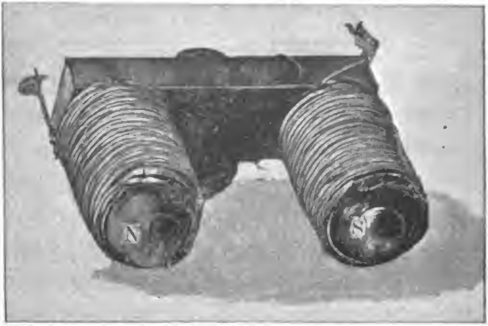

FIG. 21.—HORSESHOE ELECTROMAGNET.

ity at *B*, a south pole. If the direction of the current be reversed, the poles will be reversed, that at *A*, becoming south, and that at *B*, north. The core being of very soft iron will attain its magnetism almost immediately after the application of the

current, and will lose it as rapidly, after the cessation of the current. In this case the magnetic flux permeates the space surrounding the magnet only during the time the current passes through the coil, and the flux disappears when the current is withdrawn.

Fig. 21 shows a form of horseshoe electromagnet which is usually employed when powerful electromagnetic attractions are required.

Returning to Fig. 20, if no electric current is passing through the turns of the coil *C*, the entire magnetic attraction exerted upon the diaphragm will be that due to the flux from the permanent magnet. If a current be now passed through the coil in such a direction that the flux produced electromagnetically will be in

the same direction as that from the permanent magnet, the flux will be intensified at the pole, and the attraction exerted upon the diaphragm will be increased. If, on the contrary, the current circulates around the coil *C*, in the opposite direction, so that its flux will be opposed, or in a direction opposite to that produced by the magnet, the resulting flux from the pole will be weakened and the attractive force exerted upon the diaphragm will be decreased. Increasing the attractive force causes the plate to bend inwards; decreasing the attractive force allows the elasticity of the plate to bend it outwards, towards its original position. If, now, an alternating current be passed through the coil, the magnetic flux will be alternately intensified and rarefied at the pole, and the attractive force on the plate will be correspondingly intensified and weakened, so that the plate

will be thrown into vibration with a frequency, which will be that of the alternating current, and with an amplitude, which will depend upon the current strength.

A great variety of experiments have been tried with diaphragms of various forms and supported in various ways, but the best results have been obtained with a circular diaphragm rigidly supported or clamped all around its edge. An inspection of Fig. 11, will show the manner in which this is effected. A diaphragm will reproduce sounds even when of 1/8″ thickness or more, but the best results are obtained when the diaphragm is only about 10 mils thick. An increase in the diameter of the diaphragm will usually increase the loudness of low-pitch sounds, but, generally, at the expense of clearness.

A longitudinal section of a double-pole receiving telephone is shown in Fig. 22.

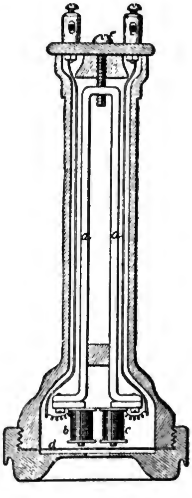

FIG. 22.—DOUBLE-POLE RECEIVER.

Here, instead of a single compound magnet, and a single pole, being presented to

the diaphragm, a horseshoe permanent magnet *a a*, is used whose two poles are presented to the diaphragm *d*, through two soft iron pole-pieces, surrounded by spools

FIG. 23.—HORSESHOE PERMANENT MAGNET.

b, *c*, wound with fine insulated copper wire. The screw *e*, between the binding posts, enables the distance between the pole-pieces and the diaphragm to be suitably adjusted. The distribution of magnetic

flux near the poles of the permanent horseshoe magnet shown in Fig. 23, is represented in Fig. 24. The magnetic flux passing through the permanent magnet of the double-pole receiver is distributed partly through the air surrounding the poles, but largely through the soft iron pole-pieces or cores, the diaphragm between them, and the air spaces between the poles and diaphragm. This magnetic flux produces a mechanical pull inwards upon the diaphragm, which flexes it to such an extent that the mechanical force is balanced by the elastic force of the diaphragm. When an electric current passes in one direction, through the insulated conductor wound upon the spools *b*, *c*, the magnetic flux passing through this circuit is strengthened, and when the current passes in the opposite direction, the magnetic flux passing through the circuit is

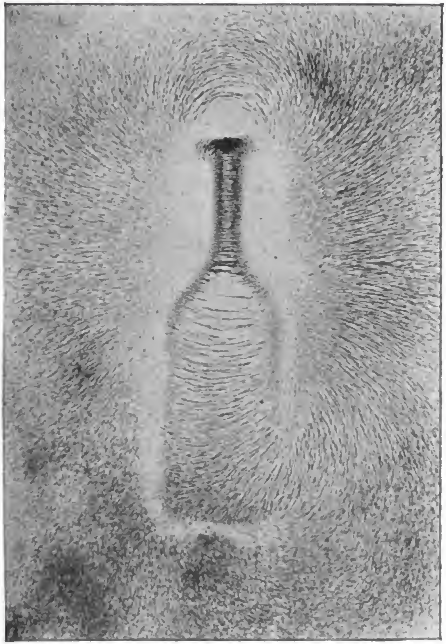

FIG. 24.—FLUX DISTRIBUTION OF PERMANENT HORSESHOE MAGNET.

weakened. Consequently, periodically alternating currents, passing through the receiver coils, produce periodically increasing and decreasing mechanical tensions exerted upon the diaphragm, and set it into vibration.

The sensitiveness of the telephone to feeble alternating currents is exceedingly great. This may be regarded as the more surprising when we consider the great simplicity of the apparatus. The current strength which can be appreciated by the telephone depends, of course, upon the construction of the apparatus, as well as upon the frequency of the current, but, with an ordinary Bell telephone, the best frequency for appreciating very feeble currents has in one case been found to be 640 per second. This corresponds, approximately, to the frequency of the note E″, of

the treble clef. At this frequency, an alternating-current strength of $\frac{4.4}{100,000,000}$ ampere produced distinctly audible sounds. Calling the millionth of an ampere a *micro-ampere*, and the billionth of an ampere a *bicro-ampere*, this current would be 44 bicro-amperes. Measurements made by different observers differ widely, some estimates of the minimum appreciable current having placed it at as low as 0.6 *tricro-ampere*, or $\frac{6}{10}$ths of the trillionth of an ampere. Even accepting the greater limit of 44 bicro-amperes, the amount of energy which would be required to be expended to maintain this current strength through the electric resistance of the telephone (75 ohms) is so exceedingly small, that the work done in lifting a 13 oz. telephone through a vertical distance of 1 foot, would

suffice to keep an audible sound in a telephone for 240,000 years!

Another form of receiver, which is in extended use, is the *watch-case receiver*,

FIG. 25.—WATCH-CASE RECEIVER.

the general appearance of which is shown in Fig. 25. This is a double-pole receiver as will be seen from an inspection of Fig. 26, which shows the arrangement of the interior. A ring of hard steel is situated

at the back of the box and is magnetized permanently across a horizontal diameter, so that opposite poles are developed at *n* and *s*. Soft iron pole-pieces are secured to the ring at this point and form the cores of

FIG. 26.—WATCH-CASE RECEIVER.

two rectangular coils, wound with fine silk-covered wire, having a resistance in all of 64 ohms. The terminals of this winding are connected to T_1, T_2. The instrument operates like the double-pole receiver already

described. The flux paths of this magnet are shown in Fig. 27. The watch-case form of telephone is almost invariably used by

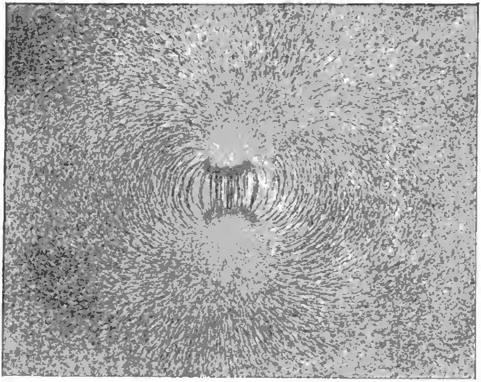

FIG. 27.—FLUX PATHS OF WATCH-CASE RECEIVER MAGNET.

operators in telephone exchanges, since it is very light (4 1/2 oz.) and is readily supported over the ear by a headband.

A form of headband is shown in Fig. 28. In using the telephone receiver, it is ad-

FIG. 28.—HEADBAND AND WATCH-CASE TELEPHONE.

visable to hold it firmly against the ear, so as to cover entirely the opening of the ear.

CHAPTER V.

THE MICROPHONE TRANSMITTER.

THE alternating currents which carry, in effect, the transmitted speech from the transmitting to the receiving end of the line, require an alternating E. M. F. to be generated at the transmitter, by the vibrations of its diaphragm. Prior to the introduction of the *carbon transmitter*, the form of transmitter now in almost universal use, the arrangement represented in Fig. 6, was generally employed, that is to say, the instrument employed as the transmitter was either identical with the receiver, or differed from it only in constructive details and not in principle. The *magneto-electric transmitter*, was, in

fact, as we have already pointed out, a small alternating-current dynamo-electric generator, in which the E. M. F. generated was produced by the influence of either a permanent magnet or an electromagnet, upon an associated coil of wire under the influence of the vibrating diaphragm. This form of transmitter was found in practice, to be comparatively feeble and, consequently, incapable of transmitting speech over long distances. Although many attempts were successfully made to strengthen the transmitted sounds, yet this strengthening was only obtained at the expense of the quality of the transmitted speech, a matter of prime importance in the commercial operation of the telephone.

The advent of the carbon transmitter marked an epoch in telephony, and some

form of this instrument is now almost universally adopted.

The carbon transmitter depends for its operation upon the principle of the *microphone*, which we shall now consider. The microphone receives its name from the Greek *mikros*, little, and *phonos*, sound, and, as its name indicates, is an apparatus for transmitting and rendering audible, feeble sounds. It consists essentially of pieces of carbon or metal in imperfect contact with one another. These pieces are included in the circuit of a voltaic cell, or battery, and a telephone. Under these circumstances, any feeble mechanical disturbance, communicated to the microphone, alters the contact surfaces, and the resistance of the same in the circuit, thereby periodically varying the current strength through the telephone. A simple form of microphone

is shown in Fig. 29. Here the imperfect contact is obtained by bridging two iron nails *C* and *C''*, connected with the circuit of the battery *P*, and telephone *T*, by a

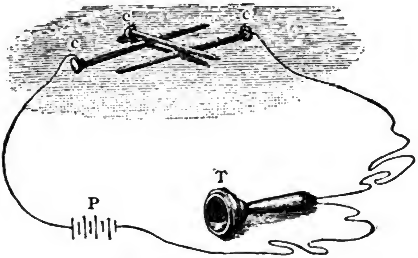

FIG. 29.—SIMPLE MICROPHONE.

third nail *C'*. A pair of loose contacts is thus produced.

When sound waves impinge against the nails, this contact is varied with a frequency which is exactly the frequency of the sound. The pressure exerted on

the bridging nail may be considered to be alternately increased and diminished, thus bringing a greater or lesser active conducting surface into contact on the nails and increasing or decreasing the resistance in the circuit. The periodic variation of the resistance produces a corresponding periodic variation of the current strength passing through the telephone, with the same frequency as that of the impinging sound, so that the telephone reproduces in its diaphragm the sounds impinging on the nails.

A simple form of carbon microphone is shown in Fig. 30. It consists of an upright carbon pencil *N*, sharpened at the extremities, and resting loosely in depressions formed in two blocks of carbon *C*, *C'*. These carbon blocks are fixed on a vertical sounding board made of thin

elastic wood and supported, as shown. *W*, *W*, are the wires making connection with the carbon blocks and leading to the

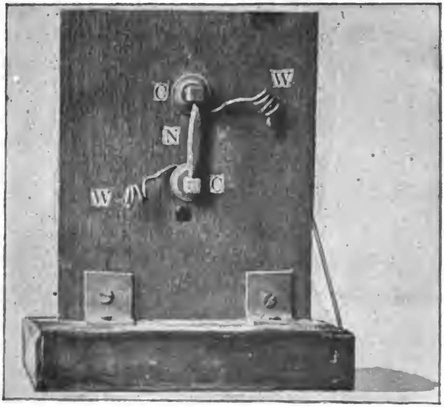

FIG. 30.—SIMPLE CARBON MICROPHONE.

telephone and battery. The loose contact of carbon, which is thus produced in the circuit, is very sensitive to variations of pressure due to impinging sound waves.

Moreover, the sound waves impinging against the extended surface of the sounding board, which transmits its vibrations to the carbon contact, render this form of instrument exceedingly sensitive. A watch, laid on the base of the instrument, will often produce a sound in the telephone like the sound of a reciprocating engine, while the tread of a fly can easily be detected. This form of carbon transmitter is not employed in telephony owing to its extreme sensitiveness to external sounds.

The advantage of carbon over any metallic substance in a microphone, arises from a variety of circumstances; namely,

(1) Carbon is practically unoxidizable and unalterable in air, and, consequently, it can be relied upon to produce permanent results.

(2) Carbon possesses, as is well known, marked powers of occluding air in its substance, that is of absorbing and condensing it, thus enabling the contact resistance to be greatly varied under variations of temperature.

(3) That whereas, ordinary metals increase in resistance with temperature, carbon possesses the valuable property of decreasing in resistance with temperature.

If we consider two surfaces of carbon in loose contact, in circuit with a continuous E. M. F., the current strength in the circuit will be controlled, within certain limits, by the resistance of this contact. If an increase of pressure at the contact takes place, as for example, by the influence of a sound wave, the first effect is to increase the active surface area of contact and thus decrease the resistance. This

increases the current strength in the circuit, and produces a local increase in temperature at the contact surface, but this increase in temperature will still further diminish the resistance of the carbon, both on account of the influence of heat on its resistivity, and also on account of its influence on the occlusion of air. The combined result is an increase of current strength in the circuit up to a certain limit, which is greater for carbon than for any other known substance.

In telephonic transmitters, as used in the United States, the carbon is almost invariably employed in a granulated condition. A simple form of such transmitter, generally called the *dust transmitter*, is shown in section in Fig. 31. *B B B*, is a wooden box to which is attached a wooden cover *C C*. The cover is pro-

vided with a suitable mouthpiece at *M*. The mouthpiece is directly over a platinum foil diaphragm *P*, clamped at its

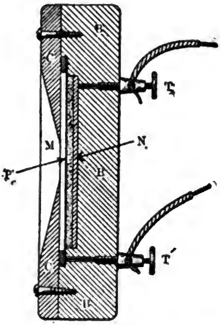

FIG. 31.—FORM OF DUST TRANSMITTER.

edge. This plate, together with a circular carbon plate *N*, forms a circular recess, nearly filled with granulated carbon. *T*, *T*′, are the terminals, one of which is connected with the carbon plate, and the other with the platinum plate. When

sound waves impinge against the platinum diaphragm, the vibrations are communicated to the granulated carbon in the

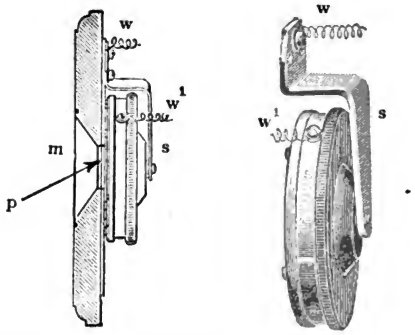

Fig. 32.—View and Section of Hunning's Carbon Transmitter.

interior. The loose microphonic contacts thus obtained, operate in the manner already described, and periodically vary the resistance between the terminals *T*, *T'*.

Another form of microphone transmitter of the same type is represented in Fig 32. Here *m*, is the mouthpiece; *p*, the platinum diaphragm, clamped over the face

FIG. 33.—CARBON TRANSMITTER.

of the box containing granulated carbon; *s*, a spring making contact with a carbon plate in the back of the box; and *w*, *w* the wires connecting the transmitter with the circuit. Fig. 33 shows the external

appearance of a microphone transmitter of this type. The use of this transmitter is open to the objection that the granulated carbon it contains is liable to cake or pack. This can sometimes be remedied by shaking the instrument. Fig. 34, shows a

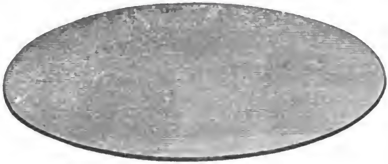

FIG. 34.—CARBON DIAPHRAGM.

carbon diaphragm suitable for use as one of the sides of a box in a microphone transmitter, thereby dispensing with the use of a platinum diaphragm.

A form of carbon transmitter in extended use, known as the *Blake transmitter*, is shown in Figs. 35 and 36. *B B B B*,

is the section of a wooden box containing an induction coil *I*, and a microphone transmitter in front of the

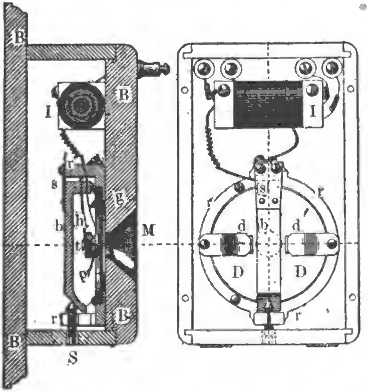

FIG. 35.—PLAN AND SECTION OF BLAKE TRANSMITTER.

mouthpiece *M*. Behind the mouthpiece is a thin sheet iron diaphragm *D D*, set in vibration by the sound waves impinging upon it. *r r*, is an iron ring supporting

an iron pendant *b*, by the spring *s*. This pendant holds two springs *g* and *h*, in its upper part. The spring *h*, holds a rather heavy brass piece *t*, to the face of

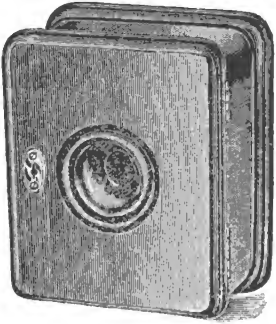

Fig. 36.—Common Form of Blake Transmitter.

which is secured a button of compressed carbon. The other spring *g*, is armed at its extremity with a platinum contact point *p*, one side of which rests in contact with the back of the diaphragm *D D*, and

the other on the surface of the carbon button. The right degree of pressure between the diaphragm, platinum point and carbon button, is adjusted by means of the screw *S*, in the base of the transmitter. The springs *g* and *h*, are insulated from each other and serve as the terminals of the transmitter. *d*, *d′*, are a pair of damping springs, resting lightly on the diaphragm *D D*, for purposes of deadening the vibrations of the latter. The functions of the induction coil will be considered in the next chapter.

A form of transmitter, called the "*solid back transmitter*," in extended use for long-distance transmission, is represented in longitudinal section in Fig. 37. *S*, is a swivel arm carrying the transmitter which is within a metallic case *m m*. Behind the hard rubber mouthpiece *M*, is the

diaphragm *D*, damped by the usual damping spring *d*. *p*, is a pin clamped by a pair of small nuts to the centre of the dia-

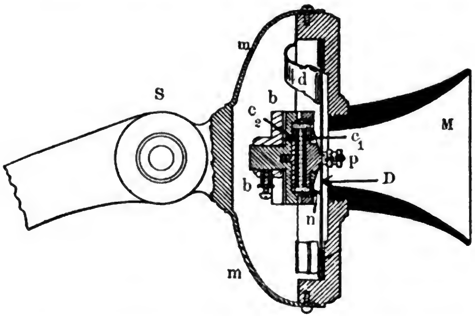

FIG. 37.—SECTION OF "SOLID BACK" TRANSMITTER.

phragm and carrying a metallic button, rigidly connected with the carbon disc or electrode c_1. A similar carbon disc c_2, let into a metallic socket, forms the back of a small circular recess partly filled with granulated carbon. The walls of the

recess are lined with paper. The front cover of the recess consists of a thin sheet of mica through which the back of the electrode $c_{,,}$ passes. The back electrode holder is securely clamped in a metallic bridge piece *b b*, supported by the frame *m m*. The vibrations of the diaphragm are communicated to the front carbon electrode $c_{,}$, through the pin *p*, the mica cover *n*, being sufficiently thin and elastic to freely permit this vibration. The carbon disc, being sensibly smaller in diameter than the recess, allows free movement of the granulated carbon particles, so that the instrument is less likely to give trouble from packing than other forms of carbon transmitters.

Besides the granulated carbon transmitters above described, modifications of the original microphone are employed. In this

type of transmitter, rods, pencils and spheres of carbon are used, arranged so as not to be as sensitive as the original form of simple microphone shown in Fig. 30.

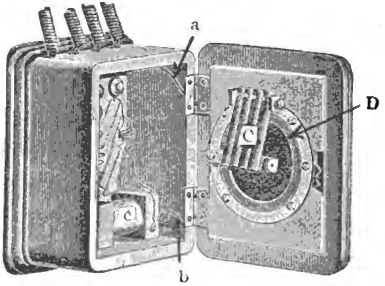

FIG. 38—FORM OF MICROPHONE TRANSMITTER.

A transmitter belonging to this class is shown in Fig. 38. Here four rods of carbon *C*, are mounted between a fixed support on the cover of the transmitter box and a frame supported on the diaphragm *D*. The wires *a* and *b*, connect through

the hinges of the cover with the terminals of the microphone. *c*, is an induction coil. The four wires leaving the box are con-

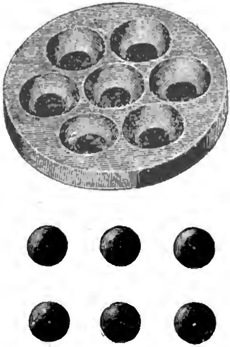

FIG. 39.—CARBON BASE PLATE WITH RECEPTACLES FOR HOLDING CARBON BALLS.

nected, two to a local battery, and two to the telephone circuit.

Fig. 39, shows a carbon base plate hollowed out for the reception of small carbon

balls employed in one form of microphone transmitter of the above type.

Fig. 40, shows another form of carbon transmitter of the above type with a single carbon ball.

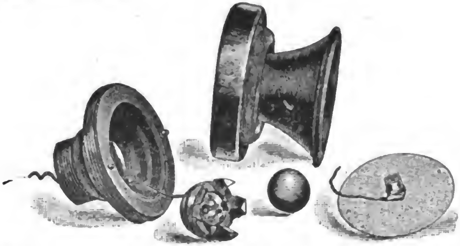

FIG. 40.—FORM OF CARBON TRANSMITTER EMPLOYING CARBON SPHERE.

In using a transmitter, it is necessary to speak distinctly, and with the lips facing the mouthpiece. The mistake is commonly made of speaking too loudly. This only unnecessarily jars the microphone. A low, clear enunciation is preferable.

CHAPTER VI.

THE INDUCTION COIL.

NEARLY all telephone circuits in use to-day employ an induction coil in connection with the transmitting apparatus. For example, such a coil as shown in connection with the transmitter in Fig. 35, and with the form of transmitter shown in Fig. 38. It will be advisable, therefore, to enter into a fairly full description of the part which the induction coil plays in telephonic transmitters. Before doing this, however, we will briefly consider some of the general principles of the induction coil.

Fig. 41, shows a common form of induction coil for use on telephonic circuits. A

hollow wooden spool, 2 1/2″ in length, with large square ends *S*, *S′*, is wound with two separate insulated conductors. The first conductor, called the *primary coil*, consists of comparatively few turns of in-

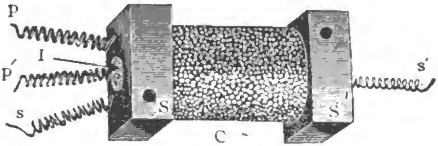

FIG. 41.—TELEPHONE INDUCTION COIL.

sulated copper wire, the ends of which are brought out at *p*, *p′*. The resistance of the primary coil is usually about half an ohm. The second conductor, called the *secondary coil*, consists of a comparatively large number of turns of fine insulated copper wire, the ends of which are brought out at *s*, *s′*. The resistance of the secondary circuit is usually about 250

ohms. The interior of the wooden spool is filled with a core of soft iron wires.

A longitudinal section of a form of induction coil similar to the above is shown

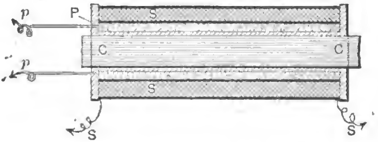

FIG. 42.—LONGITUDINAL SECTION OF INDUCTION COIL.

in Fig. 42. Here *C C*, is the core of iron wires, *P*, is the primary coil terminating at the wires *p*, *p*. *S*, is the secondary coil terminating in the wires *S*, *S*.

Fig. 43, is a diagram of a simple telephonic circuit employing a voltaic battery *E*, a microphone transmitter with diaphragm *D*, carbon microphone *C*, two

conductors l_1 l_1, l_2 l_2, and a receiving telephone T. Let us suppose that the line is 10 miles long, so that the total length of wire is 20 miles.

The resistance of the telephone will be say 75 ohms; the resistance of 20

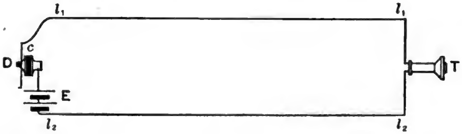

FIG. 43.—DIAGRAM OF SIMPLE TELEPHONIC CIRCUIT WITHOUT INDUCTION COIL.

miles of No. 12, A. W. G. wire, 0.0081″ diameter, approximately, 174 ohms; the resistance of two cells of battery, 3 ohms; the resistance of the microphone transmitter, 3 ohms. The total resistance of the circuit will be 255 ohms.

If the E. M. F. of the two cells employed be 1.5 volts each, the total E. M. F. in the circuit will be three volts, and, by Ohm's law, the total current strength will be $\frac{3}{255}$ = 0.01176 ampere = 11.76 milliamperes.

The effect of sound waves impinging upon the transmitter diaphragm *D*, is to cause the resistance in the circuit at the carbon microphone *C*, to vary periodically between the values of, say 2.5 and 3.5 ohms. In other words, the circuit whose resistance is normally 255 ohms to steady currents, can be varied periodically within a range of 1 ohm, with frequency and amplitude of variation corresponding to the frequency and amplitude of vocal sound waves. This range amounts to 1 part in 255, or less than 1/2 of 1 per cent.

The variations of current strength established in the circuit through the action of this minute variation in resistance, act upon the receiving telephone *T*, with practically the same strength as if the steady currents were entirely absent and the variational current acted alone in the circuit, that is to say, the effect of a continuous current, varied periodically within a minute range, is practically the same in the telephone as an alternating current having for its amplitude the range of variation in the continuous current, so that 1 milliampere of current variation, in a total current strength of 100 milliamperes, would produce a continuous current in one direction, varying between 99 1/2 and 100 1/2 milliamperes, while the effect on the telephone would be practically the same as an alternating current periodically varying between +1/2 and −1/2 milliampere.

In Fig. 44 the same telephonic circuit is represented as in Fig. 43, with the exception, that the battery is not introduced into the main circuit, but into a local circuit at the transmitting end, including the carbon microphone *C*, and the primary coil *p*, of the induction coil. The secondary coil *s*, of the induction coil is connected directly to the line.

The resistance of the local circuit containing the microphone is as follows:

Carbon microphone, say	3	ohms.
Primary coil, .	"	0.5 ohms.
Battery, . .	"	3 ohms.
		6.5 ohms.

The current strength, which will flow normally through this circuit, will be, $\frac{3 \text{ volts}}{6.5 \text{ ohms}} = 0.4615$ ampere $= 461.5$ mil-

liamperes. The same range of variation of resistance in the carbon microphone of 1 ohm thus represents a variation of 1 part in 6 1/2, or more than 15 per cent., so

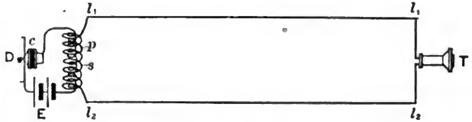

Fig. 44.—Diagram of Simple Telephonic Circuit with Induction Coil.

that as far as resistances in the microphone circuits of Figs. 43 and 44 are concerned, the range of variation in the local circuit of Fig. 44 can effect the current strength nearly 40 times more than in Fig. 43. We shall now examine how this current variation in the primary circuit is enabled to change the current strength in the main circuit.

It has already been pointed out in connection with Figs. 20 and 21, that if an insulated conducting wire be wrapped around a core of soft iron, this iron core will become magnetized during the passage of an electric current through the coil. The magnetic flux passes through the core and coil in a direction depending upon the direction of the current through the magnetizing coil, and completes the magnetic circuit through the air surrounding the core in the manner already described.

Returning to Fig. 42, if a continuous current be passed through the primary winding *P*, around the core of soft iron, it will magnetize this latter and produce a magnetic flux, which, in completing its circuit, will pass through both the primary and secondary coils, thus becoming linked with both the primary and secondary con-

ductors. This is represented diagrammatically in Fig. 45, where a current maintained in the primary winding *P P*, produces a magnetic flux whose distribution

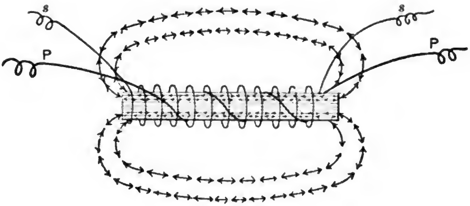

FIG. 45.—DIAGRAM OF MAGNETIC FLUX IN MAGNETIC CIRCUIT OF INDUCTION COIL LINKED WITH PRIMARY AND SECONDARY WINDINGS.

is indicated by the dotted lines enveloping the system. Since the core forms a portion of the magnetic circuit, and both primary and secondary coils encircle the core, it is evident that the magnetic flux threads through, and is linked with, both primary and secondary windings. In other words,

the magnetic circuit becomes linked with both electric circuits. This condition of affairs will be steadily maintained as long as the current in the primary circuit is steadily maintained.

If during the maintenance of this condition the secondary terminals are joined together, no current will flow through the secondary coil. That is to say, the presence of a fixed quantity of magnetic flux, threading through or linked with the secondary coil, does not produce in the latter any E. M. F.; and, therefore, cannot cause any electric current to flow when the terminals of the secondary coil are connected. If, however, the magnetic flux, so linked with the secondary coil, be increased or diminished, an E. M. F. will be induced in the secondary winding, which will cause a current to flow in the second-

ary circuit when the terminals *S*, *S*, are connected. If the flux be increased in strength, the E. M. F. will be in one direction; if the flux be diminished, the E. M. F. will be in the opposite direction.

The general law is as follows: when magnetic flux is threaded through or linked with a conducting loop, an E. M. F. is generated in that loop; if the flux so threaded be increased, an E. M. F. is generated, still in the same direction, during the time in which the increase is taking place. Similarly, when the flux linked with the loop is decreasing in strength, an E. M. F. is induced in the loop in the opposite direction; and, if after the loop is completely emptied of flux, more flux is caused to enter the loop in the opposite direction to that entering in the first instance, an E. M. F. is induced in

the loop in the opposite direction to that induced by inserting the flux in the first case; or, in the same direction as that produced by decreasing the flux in the first case. The E. M. F. induced as above depends for its value upon the rate at which the flux is changing in amount through the loop. If the flux be suddenly introduced into or removed from the loop, the E. M. F. will be comparatively great, but will only last for a brief interval, since the time during which the filling takes place is but brief. On the other hand, if the flux be admitted into, or removed from, the loop gradually, the induced E. M. F. will be small, but its duration will be prolonged, since the time of filling or emptying is correspondingly long. As soon as the amount of flux passing through the loop is steady, whether it be filled or empty, the induced E. M. F. ceases, and only exists

while a change in the flux is taking place.

Since the secondary winding of a telephone induction coil contains many turns of wire, usually about 4,000, and since each turn or loop of this winding has an E. M. F. induced in it by any change in the flux linked with the coil, all these E. M. Fs. will be in series with each other, and will be summed or added together, so that the total E. M. F. between the secondary terminals will be, approximately, 4,000 times as great as if the secondary winding consisted of but a single turn. The object, therefore, of having many turns of wire in the secondary coil is to induce therein a powerful E. M. F. when the magnetic flux passing through it, and produced by the excitation of the primary coil, is varied.

If the connections are arranged as shown in Fig. 41, and the resistance of the carbon microphone and battery are constant, the current strength passing through the primary winding under the conditions above assumed, will be steady at 0.4615 ampere. This will produce a steady magnetic flux passing through both primary and secondary coils. At the first excitation of the primary coil; *i. e.*, when the primary circuit is first closed, the introduction of this flux will induce an E. M. F. in the secondary, but as soon as the current has become steady, no further E. M. F. in the secondary coil is induced.

If now, sound waves impinge upon the transmitter diaphragm *D*, the resistance of the carbon microphone *C*, will vary, thus causing the primary current to vary. This variation of the primary current will, in

its turn, produce corresponding variations in the amount of flux passing through the magnetic circuit of the induction coil. These variations will have the same frequency as the frequency of the sound waves, and will, moreover, follow in amplitude the amplitüde of the sound waves. This variation of the magnetic flux linked with the secondary coil will induce an E. M. F., alternating in direction with the frequency, and following the changes in the amplitude, of the sound waves; for, at each increase in the primary current and magnetic flux, the E. M. F. in the secondary circuit will be in one direction, while at the following decrease, the E. M. F. in the secondary circuit will be in the opposite direction. Consequently, the varying current in the primary circuit induces an alternating E. M. F. in the secondary coil.

If the secondary coil be closed through the telephone line and receiver, as shown in Fig. 44, this alternating E. M. F. will establish an alternating current through the circuit, of frequency corresponding to that of the sound waves at the diaphragm.

The function of the induction coil is, therefore, two-fold. In the first place it enables the microphone to be removed from the main circuit, where its variation of resistance would be an inappreciable fraction of the total resistance of the circuit, and placed in a local circuit of low resistance, where its range of variation of resistance becomes a comparatively large fraction of the total resistance of the circuit, and the variation of current produced in such circuit is, therefore, correspondingly large. In the second place, the variation in current strength is employed

to induce magnetically, in the main circuit, a comparatively high alternating E. M. F. and, consequently, a comparatively strong alternating electric current, by employing many turns in the secondary coil, so that the effect of the variations in the magnetic flux, due to variations in the primary current, may be correspondingly magnified, the object being to produce as powerful an alternating-current strength in the receiving telephone as is possible.

The E. M. F. which may be induced in the secondary winding of a good telephone induction coil, by powerful vocal sounds uttered before the transmitter diaphragm, may amount to more than 100 volts. That is to say, if a certain note be sounded powerfully before the transmitter, the amplitude of the current variation in the primary circuit may suffice to

induce in all the turns of the secondary coil a total E. M. F. exceeding 100 volts; but, when the secondary coil is closed through the telephone line, the E. M. F. produced at the terminals of the line; *i. e.*, at the terminals of the secondary coil connected to the lines, may only be about 10 or 15 volts. This is owing to what is called the *drop of pressure*, or *drop of voltage*, in the secondary coil itself.

If a continuous-current strength, of say, 1 milliampere, flowed through the secondary coil from an imaginary voltaic battery within it, and if the resistance of the secondary coil were, say 5,000 ohms, the drop of pressure, which would occur under these conditions in the secondary winding, would be $\frac{1}{1,000}$ ampere $\times$ 5,000 ohms $=$ 5 volts, and with such a current strength,

the pressure or voltage at the terminals of the coil would be 5 volts less than the E. M. F. of the imaginary battery inside the coil. In the case of secondary alternating currents, however, the drop of pressure which occurs is much greater than that which would take place with continuous currents for two reasons. In the first place, the secondary currents magnetize the core in the opposite direction to the primary current, and, therefore, oppose or weaken the magnetic flux through the magnetic circuit, thereby diminishing the induced secondary E. M. F. In the second place, such induced E. M. F. as remains active, in sending a current through the secondary coil, has to overcome not only the ohmic resistance, which would be offered to the current if continuous and steady, but also an additional *apparent resistance* owing to the *counter E. M. F.*

(abbreviated *C. E. M. F.*) induced in the secondary coil by the passage through its turns of its own magnetic flux; that is to say, the secondary coil when active in producing a secondary current, produces a magnetic flux through both the primary winding and core and through itself.

In so far as this magnetic flux effects the primary winding and core, it reduces the total magnetic flux through the magnetic circuit as already mentioned. In so far as it acts through the secondary coil, considered independently, it induces an E. M. F. in itself, just as the introduction of magnetic flux through it from the primary, induces E. M. F.; but, the self-induced E. M. F. is always opposed to the primary induced E. M. F. and thereby becomes a C. E. M. F., or opposes and weakens the resulting secondary current.

This is generally expressed by saying that an alternating current finds in its circuit an *impedance*, or *apparent resistance*, which is greater than the real resistance of the circuit, such as would be found with a steady continuous current, and called the *ohmic resistance* to distinguish it from the apparent resistance, or impedance.

Impedance increases with the frequency of alternation, so that a secondary coil, which might offer, say 250 ohms to a continuous current, offers, apparently, owing to the influence of self-induction, say 2,000 ohms impedance to a current which alternates with a frequency of 300~ per second. In other words, in dealing with alternating-current circuits, Ohm's law must be extended to include the impedance, and not merely the resistance, of the circuit.

Electrically, therefore, we may regard an induction coil as a device for establishing at the terminals of the telephone lines an alternating E. M. F. having the frequency or frequencies of the sound waves produced before the transmitter diaphragm, and having an amplitude which will follow these sounds, and which is only about 10 or 15 volts with powerful sounds, and which may fall to a fraction of a volt with weak sounds.

The iron core of the telephonic induction coil is always made up of a bundle of parallel fine soft iron wires, instead of a single solid cylinder or bar of iron, that is to say, it is always a *laminated core.* Otherwise the rapid variations of magnetic flux passing through the core would induce in its mass E. M. Fs. according to the regular law already stated. These

E. M. Fs. would be objectionable for the reason that they would produce powerful secondary currents around the iron cylinder, opposing, by their own magnetic flux, the magnetic flux produced by the excitation

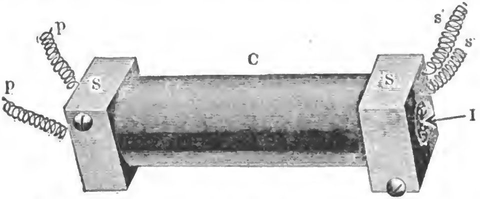

FIG. 46.—LONG-DISTANCE TELEPHONE INDUCTION COIL.

of the primary coil, and, therefore, diminishing the magnetic flux in the magnetic circuit threading the secondary coil, and consequently, diminishing the induced secondary E. M. F. When the iron core is broken up, into a number of very small cylinders, this effect, while it still takes place, is so far reduced as to be

negligible, since the E. M. F. induced and acting in each cylinder is greatly weakened, while the resistance of the circuit in which it acts is greatly increased. The higher the frequency of the sounds, which the telephone has to transmit, the more important does the lamination of the iron core of the induction coil become.

Fig. 46, shows an induction coil suitable for long-distance telephony. It differs from the one shown in Fig. 41, in being longer and having more wire in the secondary coil. The resistance of the secondary coil may be as high as 750 ohms.

CHAPTER VII.

CALL BELLS AND BATTERIES.

When a telephone is not in use, it is necessary to leave its connections so that the correspondent at the other end of the line is capable of calling attention by causing a bell, known as a *call bell*, to ring. The source of electric current for this purpose is generated by a small hand dynamo machine called a *magneto-electric machine*. The general appearance of a *hand generator*, mounted on a wooden base, is shown in Fig. 47. Here three permanent horseshoe magnets *M*, *M*, *M*, are supported in a vertical position with their like poles *n*, *n*, *n*, connected to an interior pole piece.

Between the poles of the magnets, is driven an armature consisting of an iron spindle or core provided with coils of in-

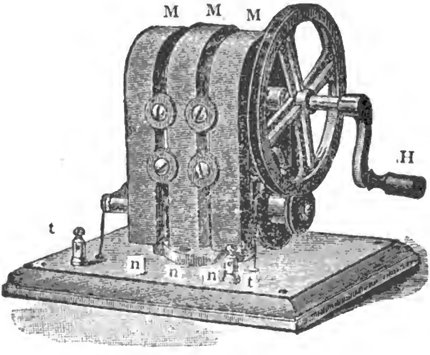

FIG. 47.—HAND GENERATOR.

sulated wire. The armature is represented in Fig. 48, where *A*, is the cross-section and *B*, a side view. This spindle or armature is rotated by the handle *H*. The ends of the wire *a*, *b*, on the revolving

armature are connected by means of rubbing contacts with the terminals *t*, *t*, Fig. 47.

A diagrammatic view of the magneto generator, and its connections with the call

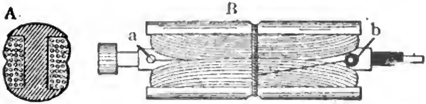

FIG. 48.—CROSS-SECTION AND SIDE VIEW OF MAGNETO ARMATURE.

bell, are shown in Fig. 49. Here the armature *A*, is wound with a great number of turns of wire (usually about 4,000) of which only four are indicated in the drawing. In the position shown, the magnetic flux from the magnet does not pass through the winding on the armature, but directly from the north pole across to the south pole through the air and through

the heads of the armature, as at *A*, in Fig. 50. When the armature is turned by the handle, through an angle of 90°, the flux

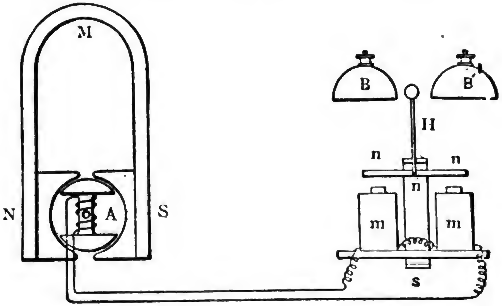

Fig. 49.—Magneto Generator and Bell.

streams will pass from the north pole to the south pole, directly through the turns of wire wound on the armature as at *C*, Fig. 50, and, during the process of threading through the armature as at *B*, Fig. 50, they will induce an E. M. F. in the wind-

ing, which sends a brief current in one direction through the bell circuit. On continuing the rotation through another 90°, the armature occupies the position

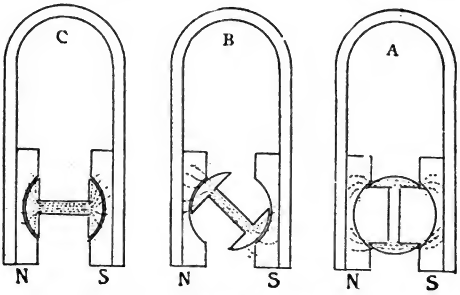

FIG. 50.—DIAGRAM SHOWING MAGNETIC FLUX THROUGH GENERATOR ARMATURE IN DIFFERENT POSITIONS.

shown in Fig. 49, but with the ends reversed. The flux will, therefore, be withdrawn from the armature and will pass through its heads only. During withdrawal, an E. M. F. will be induced in the

turns of wire, but in the opposite direction to that induced during the original introduction of the flux. On continuing the rotation for a third quadrant the flux will again be introduced, but now in the opposite direction, relatively to the winding, to that in which it entered during the first quadrant. Consequently, an E. M. F. will be induced in the reverse direction to that during the first quadrant, or in the same direction as that during the second quadrant. Finally, when the armature has advanced through its fourth quadrant, returning to the position shown, by completing the revolution, the flux will again be withdrawn from the core and coil, thus reversing the E. M. F. induced in the winding, and causing it to have the same direction as during the first quadrant. Consequently, during one complete rotation of the armature, starting with the position

shown, the E. M. F. will be in one direction during the fourth and first quadrants, and in the opposite direction during the second and third quadrants.

In other words, the E. M. F. induced in the winding will be alternating, and will have two reversals, or one complete cycle for each revolution of the armature. The faster the armature is rotated, the greater the frequency of alternation of the E. M. F.; and, since the process of filling and emptying the armature loops with flux is accelerated, the amplitude of the E. M. F. will be correspondingly increased. Consequently, in order to generate a comparatively powerful E. M. F. in the winding of this hand dynamo, it is necessary to rotate the armature at a comparatively high speed, and to wind it with many turns of fine wire. The gearing

between the hand wheel and the armature is usually about 4.6, so that the speed of revolution of the armature is nearly five times as great as the speed of the hand wheel. With three revolutions of the hand per second, the armature will make, therefore, 13.8 revolutions per second, and the frequency of alternation will be 13.8 per second. The E. M. F. produced by an ordinary telephone hand generator is nearly 60 volts. At this frequency the resistance of the armature is only about 550 ohms, but the impedance of the armature to alternating currents of vocal frequencies is enormously great, that is to say, the apparent resistance which the armature would offer to telephone currents having a frequency of say 300~ would be over 10,000 ohms.

The call bell is represented diagrammat-

ically in Fig. 49. *m*, *m*, are two electromagnet coils connected in series. Their total resistance may be from 50 to 1,000 ohms, according to the length of the circuit upon which they are designed to operate. A permanent magnet *n s*, is arranged with one pole, say the south pole, connected to the yoke or base of the two electromagnets *m*, *m*, and with its other pole in close proximity to an armature of soft iron *n n*, free to move about a horizontal axis. The motion of the armature, alternately to the right and left about this axis, will cause the hammer *H*, to strike the bells *B*, *B'*, alternately. When no current flows through the magnet coils, the armature *n n*, falls over to one side or the other and remains in that position, the magnetic flux from the permanent magnet completing its circuit most readily through the side to which the armature

lies. When a current flows through the circuit *m*, *m*, one of the cores has its magnetism intensified by the magnetic action of the current, while the other has its magnetism weakened. The result will be that the armature is either attracted more powerfully over to its adjacent pole-piece, or it is more powerfully attracted by the neighboring pole. A succession of alternating currents, provided their frequency be properly related to the natural frequency of vibration of the armature and hammer, will cause this to vibrate with the same frequency and to ring the bells. The impedance of the bell magnets is usually about 5,000 ohms at conversational frequencies.

Fig. 51 shows the interior, and Fig. 52 an exterior view, of a magneto generator and call bell very commonly employed.

M, *M*, are two permanent magnets between the poles of which an armature is driven by gearing from the handle *H*.

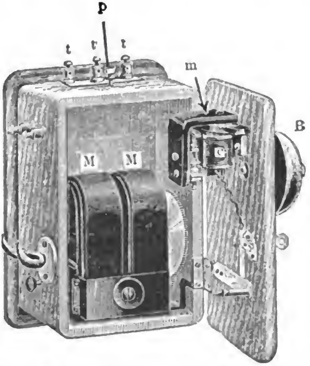

FIG. 51.—MAGNETO GENERATOR AND CALL BELL.

B, *B*[1], are the bells between which plays the hammer, under the control of a pair of electromagnet coils *c*, and a permanent magnet *m*. *t*, *t*, *t*, are the three terminals of the apparatus, the outside terminals be-

ing those which connect the apparatus with the circuit, and the middle terminal being connected to ground for lightning protec-

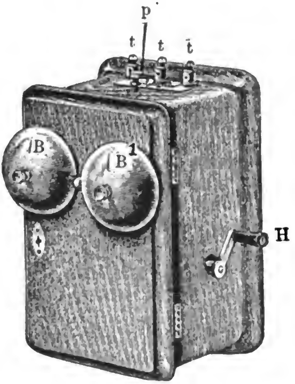

FIG. 52.—MAGNETO GENERATOR AND CALL BELL.

tion, in a manner which will be subsequently described. A small plug *p*, is provided for the purpose of enabling the apparatus to be *short-circuited*, or electri-

cally connected directly across the terminals, so as to cut the apparatus out of the circuit when so desired.

The turning of the handle of the hand generator induces an alternating E. M. F. of nearly 60 volts and replaces a voltaic battery of from 30 to 60 cells which would be otherwise necessary. So sensitive is the combination of hand generator and call bell, that the generator will produce a current sufficient to ring the bell through an external resistance of 20,000 ohms in some cases. The sensitiveness of the apparatus in this respect enables it to be frequently used for testing purposes, not only in telephony but also in other applications of electricity. A form of *testing magneto and bell* is shown in Fig. 53. Here three permanent magnets, placed as shown, have an arma-

ture capable of being revolved between their pole-pieces. A small bell is supported in the upper part of the box and

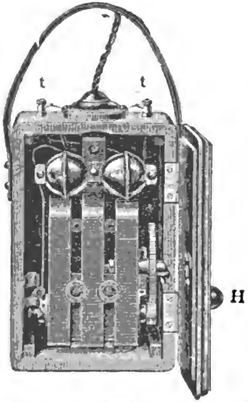

FIG. 53.—TESTING MAGNETO AND BELL.

entirely within it. This apparatus is sometimes constructed of such sensitiveness that on rotating the handle the bell will ring if the external circuit has a

resistance of 50,000 ohms or less. Consequently, when the terminals *t*, *t'*, are connected with a circuit which is to be tested, if the bell will not ring when the handle

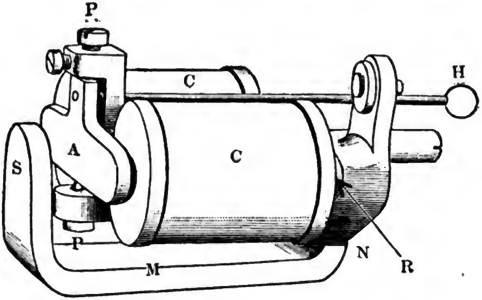

FIG. 54.—CALL-BELL MECHANISM.

is turned the circuit has a resistance of more than 50,000 ohms.

A more detailed view of the mechanism in a particular form of call bell is shown in Fig. 54. Here *M*, is a permanent magnet

having its poles at N and S, the base N, being also the yoke for the electromagnet cores, one of which is shown at R. C, C, are the magnetizing coils on the core of the electromagnet. A, is the armature pivoted on the axis P P, and supporting the hammer H. On the passage of alternating currents through the magnetizing coils, which are connected in series, the armature is thrown successively to one side and to the other, thereby actuating the bells from the hammer H.

In some cases a telephone has to be installed in such a position in a house that the occupants may at times be beyond hearing. In such cases it is found advisable to install an additional bell away from the apparatus, but in the same circuit as the call bell, so that the attention of the subscriber may be aroused even though he

be out of earshot of the main bell. Since such an additional bell virtually extends the radius of audition, it is called an *exten-*

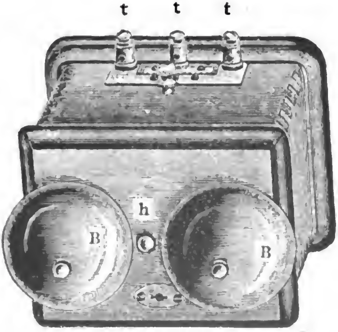

FIG. 55.—EXTENSION BELL.

sion bell. Fig. 55 shows a form of such bell. *B*, *B*, are the bells, *h*, the hammer, projecting through the cover. *t*, *t*, *t*, are the two line terminals and the ground terminal as before. The mechanism is the same as that of the ordinary bell.

When it becomes neccessary to constantly call subscribers, as from a telephone exchange, it is convenient to employ a small alternating-current gener-

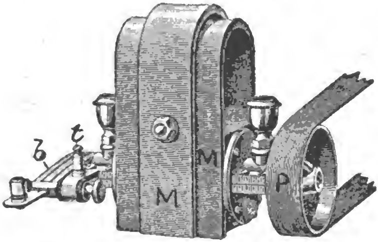

FIG. 56.—SMALL POWER-GENERATOR FOR CENTRAL EXCHANGES.

ator driven by power. Such a generator is represented in Fig. 56. *M*, *M*, are the magnets, *P*, the pulley for the driving belt, *b*, a copper brush maintaining contact with the revolving spindle, and *t*, *t*, the terminals. In some cases the generator is driven by a small electric motor, directly coupled, as

shown in Fig. 57, where *G*, is the generator of alternating currents, and *M*, is the motor which drives it through the shaft coupling *c*.

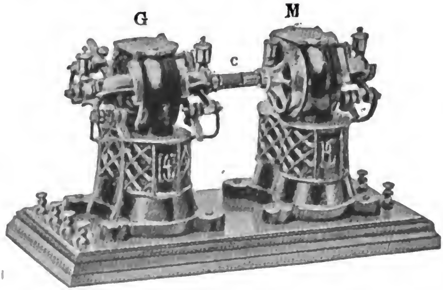

FIG. 57.—DIRECTLY-COUPLED GENERATOR AND MOTOR.

Although a voltaic battery is never employed to ring the call bells at the distant station, yet a voltaic battery is always required, as we have already seen, in connection with a microphone transmitter and

induction coil. In a voltaic battery the electric energy is obtained at the expense of the chemical potential energy of a metal and a liquid. The metal is usually zinc. The liquid, called the *electrolyte*, is either alkaline or acid, and is capable of entering into combination with the zinc during the action of the cell.

Every voltaic cell consists essentially of two dissimilar metals or *elements*, or substances called a *voltaic couple*. Voltaic cells are constructed in a great variety of forms and may conveniently be divided into two classes called *single-fluid cells* and *double-fluid cells*, according to whether a single electrolyte surrounds both the elements of the cell, or whether a separate electrolyte is provided for each element. In the latter case the two electrolytes or fluids are either separated by their differ-

ence of density, or by means of a *porous cell* or cup.

The first voltaic cells that were devised consisted of a plate of zinc and a plate of copper immersed in dilute sulphuric acid. The E. M. F. supplied by a single cell of this description is, approximately, 1 volt. When, however, the cell is allowed to send an electric current through an external circuit, the solution rapidly becomes decomposed, the zinc dissolving and forming zinc-sulphate, while, at the copper plate, hydrogen gas is liberated in corresponding quantities. This hydrogen gas, adhering to the surface of the copper plate, develops a secondary voltaic cell, in which the zinc on one side and the hydrogen on the other are the elements, so that the E. M. F. of a hydrogen-zinc couple is opposed to, or acts as a C.

E. M. F. to the original E. M. F. of the copper-zinc couple. Consequently, the E. M. F. of the cell rapidly weakens during use, or the cell is said to become *polarized.*

Hundreds of different forms of cells have been tried since the production of this primitive form, and almost entirely with the view of developing an E. M. F. which would be steady, that is a cell which would be free from polarization. Polarization is obviated in two ways; first, by introducing a liquid immediately around the copper plate; or, what corresponds to the copper plate; *i. e.*, the *negative element*, so as to combine chemically with the hydrogen as it forms, or prevent the hydrogen from forming. Such cells are called *double-fluid cells*, because a second fluid is employed to surround the

negative plate. The second method employs only one fluid in the cell, but employs a solid substance in the immediate neighborhood of the negative plate, which enters into combination with the hydrogen, and so prevents it from forming. The method is in both cases the same, but the details differ in each case.

Some cells are so completely protected that they do not sensibly polarize even under prolonged action. Other cells do sensibly polarize, but have the property of recovering rapidly, or becoming *depolarized,* when sufficient intervals of rest are allowed. These cells are called *closed-circuit* and *open-circuit cells* respectively. Since telephonic service is usually intermittent, the cells employed for telephonic purposes are often of the open-circuit variety.

From a purely electrical point of view a voltaic cell is an apparatus for producing an E. M. F. with a certain quantity of contained or associated resistance. The E. M. F. of the cell depends only upon its type, that is to say, upon the chemical activities it contains and not upon its size. In other words, having a cell of a given type, the E. M. F. will be the same whether the cell has the size of a barrel, or the size of a thimble, but the strength of current, which can be obtained from cells of different sizes, is, of course, very different. The resistance of the cell, or its *internal resistance*, as it is called, diminishes as the size of the cell is increased. It depends upon the length and cross-sectional area of the *electrolyte*, or liquid between the plates, and also upon the nature of the electrolyte. In other words, the cell has the resistance which would be

offered by a wire having the length and cross-sectional area of the liquid between the plates, and the resistivity of the liquid. Liquid resistivities are generally enormously greater than metallic resistivities, so that the resistance of the voltaic cell is commonly 1 or 2 ohms. In special types, where the plates are brought close together and have a large surface area, the internal resistance is brought down to a small fraction of an ohm.

The E. M. F. of a voltaic cell is usually between 1 and 2 volts. Bluestone cells have an E. M. F. of, approximately, 1 volt; carbon cells, of the single-fluid type, usually have an E. M. F. of about 1 1/3 volts; chromic acid cells usually have an E. M. F. of about 2 volts. E. M. Fs. above 2 volts are rare, and E. M. Fs. above 4 volts are not known. In

order to obtain an E. M. F. greater than 2 volts from voltaic cells it is necessary to so connect a number of cells as to enable them to act as a simple cell. Such a combination is called a *voltaic battery*.

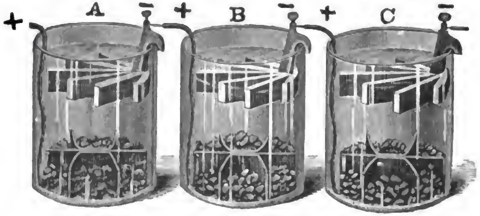

FIG. 58.—SERIES-CONNECTED BATTERY.

Fig. 58, shows a *series-connected battery* of three bluestone voltaic cells. The E. M. F. between the terminals of the battery will be, approximately, 3 volts. Here, as will be seen, the negative pole of the cell *A*, is connected to the positive pole of the cell *B*, and the same connec-

tion exists between *B* and *C*. If the resistance of each cell is 2 ohms, the total resistance of the battery will be 6 ohms. Bluestone batteries are not used in telephony, owing to the diffusion of the liquids, which rapidly causes the solution of sulphate of copper to surround the zinc and corrode it. In other words, there is considerable *local action*, or wasteful chemical action when the cell is out of use. The bluestone cell is better adapted to closed circuit work under a constant load.

A form of open-circuit cell in extended use, both for telephony and bell service, is the Leclanché cell. Here the elements are zinc for the positive, and carbon for the negative plate. The zinc is immersed in a solution of sal ammoniac in water, while the carbon is surrounded by a pulverized mixture of coke and black

oxide of manganese packed in a *porous cell;* *i. e.*, a cell which permits of the permeation of liquid through it, but prevents

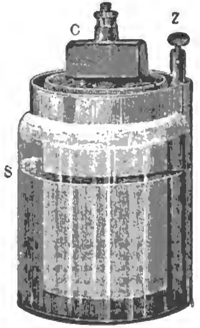

FIG. 59.—LECLANCHÉ CELL.

the passage of solid material. Such a form of cell is shown in Fig. 59. *Z*, is a zinc rod or cylinder forming the positive plate, or the negative terminal, of the cell. According to convention, the current is

assumed to enter the cell at the negative pole, leave the plate connected therewith for the liquid, in order to complete the

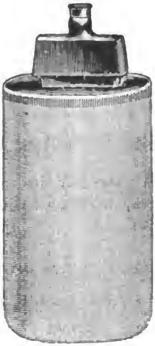

FIG. 60.—LECLANCHÉ POROUS CELL.

circuit through the interior of the cell, issuing at the positive terminal. *C*, is the carbon element forming the negative plate or the positive pole of the cell. *S*, is the level of the electrolytic solution. Such a

cell polarizes under heavy loads, but rapidly recovers on open circuit. Fig. 60

FIG. 61.—SINGLE-FLUID CARBON CELL.

represents the porous cell and its contained carbon plate, removed from the solution.

Figs. 61, 62 and 63, represent single-fluid cells of different manufacture, but all

of the zinc-carbon type. These cells differ in their details of construction and in the

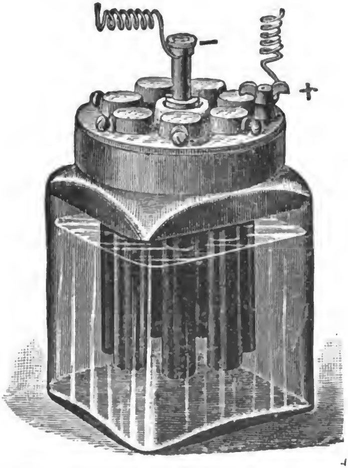

FIG. 62.—SINGLE-FLUID CARBON CELL.

electrolyte employed. In each cell the zinc rod forms the negative pole and the

positive plate, while the carbon cylinders form the positive pole and the negative plate.

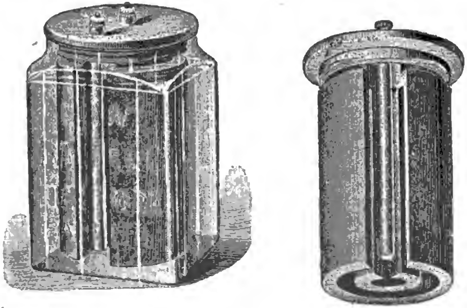

FIG. 63.—SINGLE-FLUID CARBON CELL.

Figs. 64 and 65 represent *dry cells*, often improperly called dry batteries. A dry cell is a cell in which the elements are not immersed in a liquid electrolyte, but are hermetically sealed in a chamber containing some moist gelatinous or

pulverulent material. That is to say, there is sufficient liquid in the substance filling the chamber, to enable the action of

Fig. 64.—Dry Cell.

the cell to be maintained as though a liquid electrolyte were employed. The advantage of the cell is that it can be carried about with great ease and handled without fear of spilling corrosive liquids.

On the other hand, its disadvantage lies in the high internal resistance of the cell,

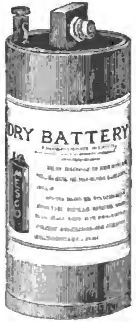

FIG. 65.—DRY CELL.

which is greater than it would be were a liquid electrolyte employed.

CHAPTER VIII.

SINGLE-CIRCUIT CONNECTIONS.

The simplest case of telephonic communciation is where a single apparatus is placed at each end of a circuit. Here the following instruments are provided at each end of the line; viz., a transmitting and receiving instrument, a call bell, a magneto generator, a cell or battery for operating the microphone transmitter, and an induction coil. This variety of telephonic apparatus is shown in Fig. 66, where *A A'* and *B B'*, are the two line wires constituting what is called a *metallic circuit;* that is, a circuit which is metallic throughout, or formed entirely of conducting wires.

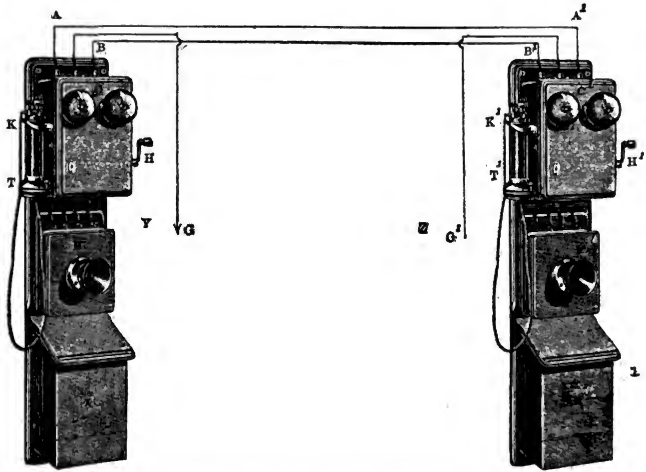

FIG. 66.—CONNECTIONS FOR SINGLE TELEPHONE CIRCUIT.

For short lines this arrangement of circuit is not necessary, one line such as A A', with a *ground-return circuit* being sufficient; that is to say, the conductor B B', is replaced by the ground, which, as is well known, is in its mass a good conductor. The third wire at each instrument marked G, G', is a *ground wire*, but does not form any portion of the telephonic circuit, being provided simply for the purposes of lightning protection, as will be subsequently described. H, H', are the magneto generator handles; T, T', the receiving telephones, which hang upon the hooks K, K'. These hooks operate *automatic switches* inside the instrument; that is to say, they automatically change the connections of the apparatus by the mere act of taking the telephone down or replacing it; M, M', are the mouthpieces of the microphone transmitters. X, X', are boxes provided

for the reception of the local voltaic cells of the induction coil. The local battery seldom exceeds two cells, while, for short lines, a single voltaic cell is sufficient.

A diagram of the connections such as they remain while the telephones are hanging in place on their hooks is shown in Fig. 67. *A A'* and *B B'*, are the line wires forming a metallic circuit. The telephone hooks *K*, *K'*, are so arranged that the weight of the telephone causes the hook to rest in electric connection with the lower contact piece 1, 1, leaving the contact springs 2, 2, and 3, 3, disconnected. On lifting the telephone, a suitably placed spring forces the hooks upwards into electric connection with 2, 2, and 3, 3, leaving the contacts 1, 1, disconnected. The circuit, as it exists with the telephones in place, is represented in the lower part of the

figure. Here, an electric current, entering the apparatus on the left hand at *A*, passes through the magnet coils of the call bell to

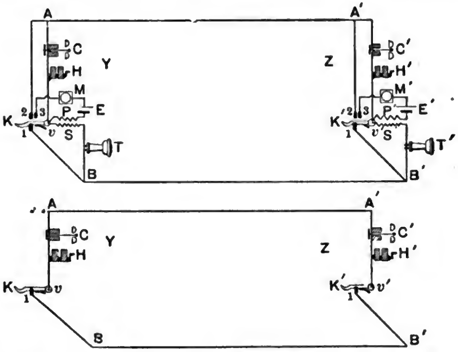

FIG. 67.—CONNECTIONS OF SINGLE CIRCUIT. TELEPHONES HANGING ON HOOKS.

the generator armature *H.* This is so arranged that when not operated it is *short-circuited*, or cut out of circuit. By turning the handle of the hand-generator, the short-circuit is broken. and the armature is auto.

matically thrown into the circuit. The current, therefore, passes by the generator to the pivot v, of the hook, through the hook to the contact 1, and thence direct to B, along the line B, B', to the telephone apparatus at the distant end through contact 1, of the hook K', to the pivot v', thence passing by the magneto armature H', through the magnet coils of the call bell C', to A', completing the circuit through the line A'. Consequently, if the resistance of the wire is 50 ohms, and the resistance of each call bell 100 ohms, the total resistance of the circuit, when the telephones are hung up, is 300 ohms.

If the person using the telephone, whom we shall hereafter for convenience refer to as the *telephoner*, desires at either station, say Y, to call up the telephone at Z, he

gives the handle H, a few rapid turns. This operation automatically inserts the armature H, into the circuit, adding its impedance to the circuit, but also adding an E. M. F. generated by the rotation. An E. M. F. of, say, 50 volts is thus brought to act in a circuit, whose impedance may be, say, 2,000 ohms, thus, sending an alternating current through the circuit of $\frac{50 \text{ volts}}{2{,}000 \text{ ohms}} = \frac{1}{40}$ ampere $=$ 25 milliamperes. This current passes through two call bells C, and C'', and rings both of them. The telephoner at Z, hearing his bell ring, goes to his apparatus and replies either by turning his handle for a moment, or by lifting the telephone T'', from the hook H'. At about the same time the telephoner at Y, will also lift his telephone T, from the hook K. The hooks will now automatically change

their contacts to the positions shown in Fig. 68. The corresponding circuit connections are shown beneath. Here an in-

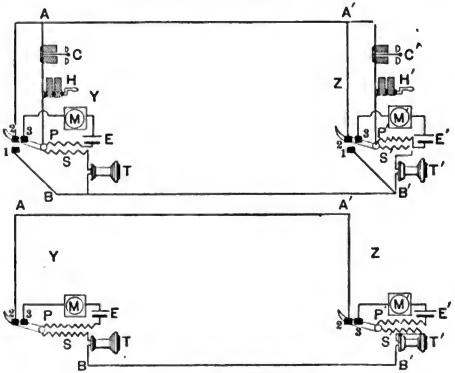

FIG. 68.—CONNECTIONS OF SINGLE CIRCUIT. TELEPHONES REMOVED FROM HOOKS.

spection of the figures will show that the bells and magneto armatures are cut out at each end, since the main-line circuit is closed through the secondary coils of the

induction coils and the telephones, while the primary circuits of the induction coils are closed through the voltaic cells and the carbon microphone transmitters.

If telephoner *Y*, speaks to his transmitter *M*, the current strength in the local circuit, is periodically varied in conformity with the vocal sound waves, and, as we have seen in Chapter VI., this produces a corresponding alternating E. M. F. in the secondary coils *S*. This E. M. F. produces an alternating current in the circuit S, A, A', S', T', B', B, T, the current traversing both secondary coils and both telephones. The impedance of the circuit is the total impedance of the lines, the induction coils, and the telephones. The E. M. F. is the induced E. M. F. in the secondary coil *S*. When telephoner *Z*, replies, the connections re-

main unchanged, the current in the circuit being now generated by vocally produced alternating E. M. Fs. in the secondary coil S'. Both telephoners can, therefore, exchange conversation. When it is desired to stop conversing they hang their telephones on their respective hooks and the circuit is once more completed as shown in Fig. 67.

Fig. 69 shows the connections for a single circuit in the case where a ground-return circuit is employed instead of a metallic circuit, and an extension bell is in use at each end of the line. In order to ground the circuit at each end of the line, it is sufficient either to connect the ground wire to metallic plates buried in permanently moist earth, or to make good soldered contact with gas and water pipes where they are readily accessible. The

resistance of the ground between two buried plates may be only a fraction of an ohm when the plates are large and buried in thoroughly moist earth even when they

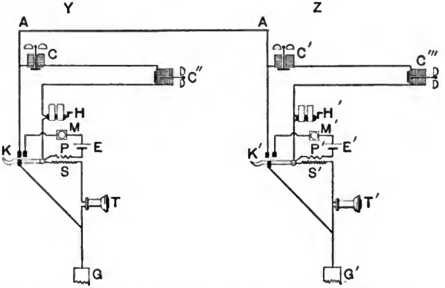

FIG. 69.—SINGLE CIRCUIT WITH GROUND RETURN.

are situated many miles apart. When resistance does exist in the ground circuit it is almost always to be traced to imperfect contact with ground, that is to say, to resistance in the ground connection, and not to resistance in the ground itself. A

metallic plate, buried in a river, or in the ocean, ensures excellent ground connection. When the circuit is completed within the limits of a single building, the gas or water pipes of the building will furnish an excellent conductor, without any necessity for the current to pass through the ground on its return path.

Fig. 70 shows a form of *magneto transmitter*. Here a powerful compound permanent magnet *M*, is provided with a coil *C*, of fine insulated wire supported in front of one of its poles on an iron core forming the pole-piece of the magnet. The iron diaphragm *d*, is clamped so as to be in close proximity to the pole-piece. When sound waves impinge upon the diaphragm, the vibrations of the latter cause the distance between the pole-pieces and diaphragm to be periodically varied,

thereby periodically modifying the magnetic circuit of the magnet, so that the magnetic flux, passing through the core and coil C, is periodically varied. This

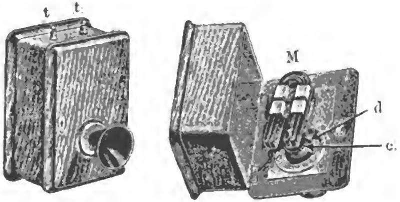

FIG. 70.—FORM OF MAGNETO TRANSMITTER.

variation of flux linked with the wire on the coil, induces in it, as we have already seen, an E. M. F. alternating in direction with the frequency or frequencies corresponding to the frequencies of the vibrations of the diaphragm.

A set of telephone apparatus employing a magneto transmitter of the above

description is shown in Fig. 71. Here the call bell, *C*, *C*, is operated by a magneto generator within the box *B*. The oper-

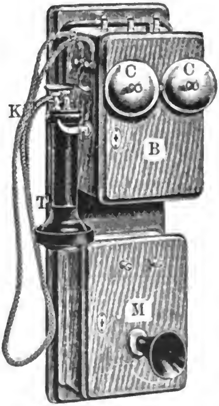

FIG. 71.—MAGNETO TRANSMITTER TELEPHONE APPARATUS.

ation of removing the telephone from its hook *K*, places the telephone in direct connection with the circuit through the

magneto transmitter coil. No battery or induction coil is required in this system, but comparatively loud speaking is necessary. The apparatus is unsuited for conversation over long lines, the magneto transmitter being feebler than the combination of microphone transmitter and induction coil.

CHAPTER IX.

MULTIPLE-CIRCUIT CONNECTIONS.

If more than two telephones are connected in a circuit, say three for example, at stations *X*, *Y* and *Z*, the inconvenience arises that when *X*, desires to call one station, say *Y*, he rings up both *Y* and *Z*. This inconvenience, while comparatively trifling with only three stations, rapidly increases as the number of stations in the circuit increases. Moreover, the impedance arising from numerous instruments in one circuit, becomes a serious matter and interferes with the telephonic transmission of speech over considerable distances. Again, telephonic communica-

tion is apt to be interrupted by the breaking in of other stations desirous of calling up. For these reasons, the number of telephones connected in a single circuit is rarely more than three. In order to insert stations into a circuit it is only necessary to interrupt the line at the location desired and introduce the new telephone apparatus, connecting the separate ends to the respective terminals.

The connection of three telephones at stations *X*, *Y* and *Z*, in a single circuit, is represented in Fig. 72. Here the line *B B′ C′ C*, is interrupted at *Y*, and the telephone *Y*, inserted as shown. The conductors *A A′*, may be replaced by a ground return, by connecting each of the wires *A* and *A′*, to ground plates. The middle terminal of each apparatus left disconnected in the figure, is provided

for connection to ground for lightning protection as is shown in connection with Fig. 66.

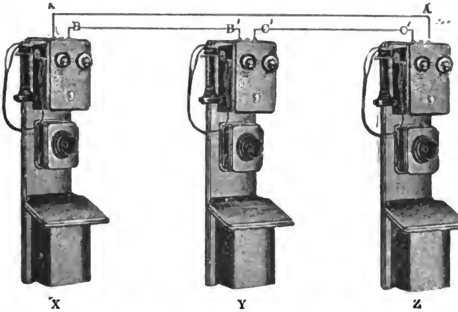

FIG. 72.—CONNECTION OF THREE TELEPHONES IN A SINGLE CIRCUIT.

When a number of telephones are connected in a single circuit, a system has, of late years, been introduced for connecting them in parallel between two lines forming the conductors of the circuit, instead of connecting them in series as shown in

Fig. 72. This system is called the *bridging-bell system*, because the bell at each station permanently bridges across the two line conductors. This system of connection is represented in Fig. 73, where

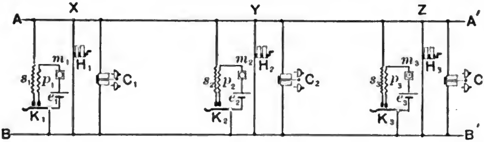

FIG. 73.—BRIDGING-BELL SYSTEM OF MULTIPLE CONNECTION TO SINGLE CIRCUIT.

A A' and *B B'*, are the two line conductors, which now pass uninterruptedly through the various stations. At *X*, *Y*, and *Z*, the bells C_1, C_2 and C_3, are permanently connected across the lines as shown. The magnet coils of these bells are wound with many turns of fine wire to a resistance of about 1,000 ohms. To low-fre-

quency currents, such as those produced by the magneto hand generator, the impedance of these coils is only about 1,100 ohms, or only about 100 ohms in excess of their *ohmic resistance* or resistance to steady continuous currents; but, at conversational frequencies, of say 300 periods per second, their impedance becomes about 4,250 ohms, and at 600 periods per second, about 8,000 ohms. During conversation along the line, therefore, the bells only act as high resistance leaks, allowing but little of the current transmitting the speech to leak through them and so fail to pass through the receiving telephone; but for calling, the bells do not offer a high impedance.

The generators H_1, H_2, H_3, are so arranged that normally one terminal lies out of contact with the circuit, but turning

the handle establishes a connection and causes the active generator to bridge the conductors, thus ringing the telephoner's own bell, as well as all the other bells on the circuit. Consequently, in this system the generators, instead of being normally short-circuited, are normally disconnected from the circuit. When a telephoner lifts his telephone from its hook, say at *X*, the hook lever rises under the tension of a spring and establishes contacts which close the local microphone circuit, and also the circuit of the telephone through the secondary of the induction coil, thus bridging the telephone across the line conductors, and enabling the telephoner to impress the speech-generated current-waves upon the circuit which will pass mainly through any other telephones that may be bridged in the same way across the lines, say at *Z*, the balance of the cur-

rent, a smaller quantity, leaking through the bridged bells.

The interior of a bridging bell generator box, with diagrammatic connections, is

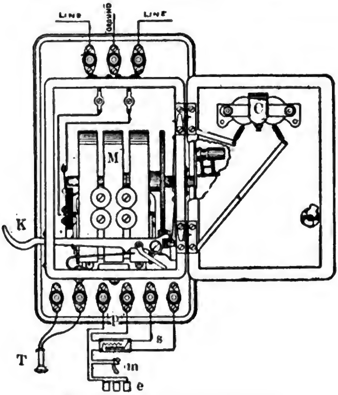

FIG. 74.—BRIDGING BELL.

represented in Fig. 74. Here the handle *H*, drives the armature of the magneto generator *M*, and in so doing establishes a

contact at the left-hand extremity of the handle axis. The hook *K*, on being permitted to rise, establishes two contacts at its right-hand extremity. *T*, is the receiving telephone; *p*, the primary winding; and *s*, the secondary winding of the induction coil. *m*, is the microphone transmitter and *e*, is the local battery. *C*, is the bell. These bells have the same general construction as those already described, but have usually longer cores and are more delicate in action.

In order to call any single station at will, it is customary to adopt a code of bell signals, so that although the bells on the circuit will respond to any call, yet each telephoner can recognize when he alone is called. This system possesses the inconvenience, however, that each telephoner has to assure himself that the line

is free from conversation before he calls up any of his correspondents. It, moreover, possesses the disadvantage that all conversation on the line can be overheard at any station. The introduction of a third telephone, bridging a circuit during conversation, merely weakens the current waves received at the telephone of the more distant listener, but does not interrupt it. In some cases, quite a number of telephones are bridged across a line in this manner. As in other systems, it is possible to replace one of the conductors by the ground and thus use only one wire.

Where a number of telephones are required to be used in one building so as to form an interconnected system; or in a number of buildings comparatively close together, and, consequently, where a multiplicity of wires is less expensive than

a single circuit to each house with a central exchange or switchboard, some automatic multiple-wire system is usually employed. An example of such a system is the *auto-telephone system*, represented in Figs. 75, 76, 77 and 78.

Fig. 75 shows the apparatus at one station for an automatic multiple-wire system arranged for a fourteen station system. That is to say, the apparatus provides for fourteen telephoners being interconnected. For this purpose a cable of sixteen insulated wires is run from station to station, and each station is connected with these wires. *T*, is the receiving telephone, which is suspended from a hook. The hook is not, however, in this case an automatic switch. *M*, is a microphone transmitter and *C*, a call bell. *K*, is a key or lever switch, capable of turning about a vertical axis.

This key rests normally in contact with the upper plate or sector cover, and is in electric connection with the same. On

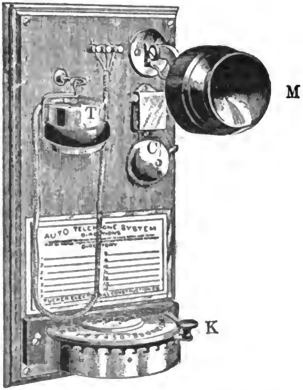

FIG. 75.—APPARATUS FOR AUTO-TELEPHONE SYSTEM.

pressing down the key this contact is broken, and the key may be locked in any one of the fourteen serrated notches in the lower sector. When so locked the key

effects two sets of contacts. Suppose, for example, that the key of telephoner No. 1, is turned to notch 3, and is locked therein. It is then out of contact with the upper plate, and establishes connection between a battery of several voltaic cells located at any convenient part of the system, and the bell of telephoner No. 3, through his special wire, while at the same time, the bell of No. 1, is set ringing. Telephoner No. 3, hearing himself called, lifts his telephone and opens it, that is to say, he removes a metallic cover from its face as shown in Fig. 76. This breaks a contact *c*, *c*, which cuts the bell out of circuit and inserts the microphone transmitter and telephone receiver. The extra resistance, thus inserted in the circuit, has the effect of reducing the current to such a strength as will fail to keep the bell at No. 1, ringing, so that both bells cease to operate.

Telephoner No. 1, then knows that No. 3 has taken up his telephone and is ready to enter into conversation. He then opens his own telephone and speaks to No. 3.

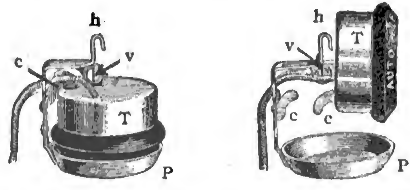

FIG. 76.—TELEPHONE CLOSED AND HUNG UP.

TELEPHONE OPEN AND IN USE.

Under these conditions, the wire belonging to No. 3 station is exclusively used and no other station can employ that wire to call up No. 3, but any other pair of stations can call up and communicate with each other. For example, Nos. 2 and 4, or 5 and 7, may call up and communicate, independently of the conversation going on

between 1 and 3. The conversation between 1 and 3, is not overheard by the other stations unless they depress their keys and listen on wires Nos. 1 or 3.

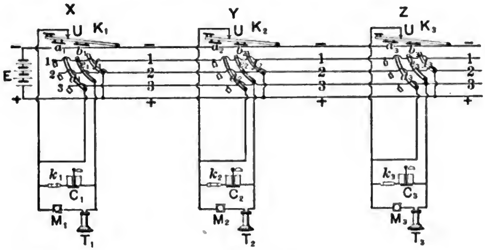

FIG. 77.—DIAGRAM OF AUTO-TELEPHONE CIRCUITS.

The advantage of the system is its simplicity, and the fact that no exchange or automatic switch is necessary.

Fig. 77 is a diagram of connections for three stations only, and, therefore, represents only five wires as connecting the

three stations. On the left hand is a battery whose poles are connected to the outside wires + and −. *a* and *b*, are two contact pieces carried by the keys. When a key, such as *K*, at *X*, is depressed at any point in the half circle, say at 3, the contact piece a_1, puts line No. 3 and the metallic sector d_1, into connection, while b_1, makes contact between sector e_1 f_1, the upper contact being broken between K_1 and *U*. If the connections are traced it will be seen that a current will be sent from the + pole of the battery through f_1 e_1, the bell C_1, the contact k_1, the sector d_1, the contact a_1, the contact 3, which is then underneath a_1, the wire 3, to station *Z*, the sector e_3, the bell C_3, contact k_3, the upper contact *U*, the key K_3, the return wire (−) and the battery. This rings the two bells C_1 and C_3, at stations *X* and *Z*. On opening the telephones for use,

the contacts k_1 and k_3, are broken, and the telephones T_1 and T_3, are brought into circuit through their respective microphones M_1 and M_3. Fig. 78 shows a desk

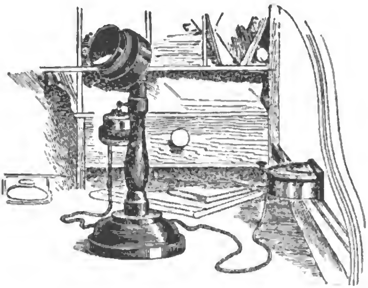

FIG. 78.—AUTO-TELEPHONE DESK SET.

set for the same system, the connections being the same as in Figs. 75 and 76.

Fig. 79 shows a set of telephone apparatus for a somewhat similar system of

interconnection of ten stations by the use of multiple wires. Instead of a key

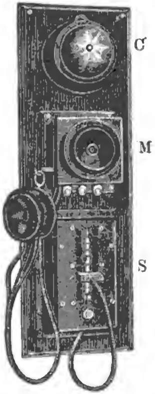

FIG. 79.—MULTIPLE WIRE TELEPHONE SET.

moving over a circuit, a double plug is inserted in each one of ten pairs of holes. Any one station can call up any other station independently of the rest,

but it is possible, by plugging successively, to overhear what is being said on other wires. This objectionable feature is common to practically all multiple circuit systems.

CHAPTER X.

ISOLATED-STATION SWITCHBOARDS.

WHEN the telephoners who require to be interconnected exceed a certain number, or where the distance which separates them is considerable, or where privacy in their intercommunication is essential, multiple-circuit connections with their multiplicity of wires are replaced by single-circuit connections provided with a device called a *switchboard* for establishing the necessary interconnections, the services of one or more operators being required at the central station where the switchboard is located. Such a switchboard may be called an *isolated-station*

switchboard, in order to distinguish it from a *central-station switchboard*, which is a more complex apparatus of the same type.

To install an isolated-station switchboard, a single circuit is wired from the switchboard to each individual *subscriber*, as the telephoner is now called. Two wires are needed when the circuit has to be metallic; and one wire, with a common ground-return, when a ground-return circuit is employed.

Fig. 80 indicates a central station *S*, with three telephone conductors running to stations *X*, *Y*, and *Z*, respectively. To simplify the connections the call bells are omitted from the drawing. Consequently, each subscriber is supposed to be stationed at his telephone. If subscriber *X*, desires to speak to subscriber

Y, he has to ask the operator at the central station *S*, to call the attention of *Y*, and then to connect the ends of *Y*'s wire to the end of the wire of *X*. This

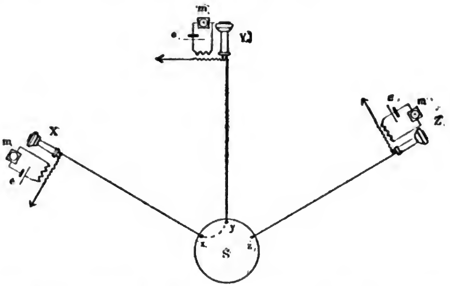

FIG. 80.—DIAGRAM OF TELEPHONE GROUND-RETURN CIRCUITS RADIATING FROM CENTRAL EXCHANGE.

connection is represented in the drawing by the dotted lines, *x y*. *X* and *Y*, are then able to converse. If subscriber *Z*, at the same time should desire to speak to either *X* or *Y*, he will ask the operator at

station *S*, to connect his wire with that of either *X* or *Y*. The operator will have to notify *Z*, that the wire he desires to be connected with is busy, *i. e.*, is connected with some other telephoner, and *Z*, has to wait until the connection in the dotted lines between *X* and *Y*, is interrupted before he can be connected with the person he desires to speak with.

Fig. 80 indicates ground-return circuits, and a single connecting wire *x*, *y*, for an interconnection at the central station. A switchboard intended for effecting such single connections is termed a *single-wire switchboard.* The development of telephony has, however, necessitated the use of metallic circuits. Fig. 81 represents the corresponding connections for three metallic circuit subscribers with a central exchange. Here two connections,

indicated by the dotted lines, are necessary to interconnect the circuits of any two subscribers. A switchboard capable

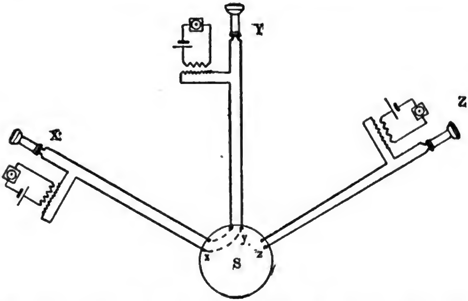

FIG. 81.—DIAGRAM OF TELEPHONE METALLIC CIRCUITS RADIATING FROM CENTRAL EXCHANGE.

of making these interconnections is called a *double-wire switchboard.*

In order, therefore, that an isolated-station switchboard can be operated, it is necessary that the operator at the switch-

board should be capable of being called up by any of the subscribers connected therewith, and that she should also be able to call the attention of any of them at will. Moreover, means must be provided for establishing communication between their respective lines, and of ascertaining when the conversation is completed, so that the connection can be discontinued. The switchboard enables all these requirements to be met.

Fig. 82 represents a *standard switch-board* for 100 subscribers as commonly employed in the United States. It consists of a vertical frame and desk before which the operator is seated. In the upper part of the frame are shown at *d*, *d*, *d*, *d*, 10 rows of 10 "*drops*" each, making 100 drops in all. These drops consist of small *electromagnetic annunciators*,

that is, mechanisms inserted in the line of each subscriber, whereby any current re-

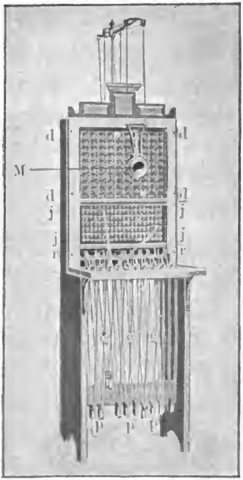

FIG. 82.—ISOLATED-STATION SWITCHBOARD.

ceived from the subscriber attracts the armature of the electromagnet and releases

a shutter thereby indicating the number of the particular subscriber calling.

Beneath the drops and at *j, j, j, j,* are 6 rows of 20 "*spring jacks*," making 120 spring jacks in all. A spring jack is a form of spring contact arranged behind the board with a hole in the board immediately in front of it for the insertion of a plug. One spring jack is inserted in the circuit of each subscriber, the extra 20 being provided for auxiliary lines. All the drops and also all the jacks are numbered from 1 to 100 so as to be readily recognized.

Immediately beneath the jacks is a single row *r, r,* of 10 drops, which are not normally inserted in the circuit of the subscribers, but only become inserted when a pair of subscribers are connected so that

conversation takes place with this drop magnet in circuit. As soon as the subscribers finish conversing, and "*ring off*," they cause this drop in their circuit to fall, and thus notify the operator that the connection between them may be discontinued. These drops are called "*clearing-out drops*" to distinguish them from the "*calling drops*" in the upper portion of the board.

The calling drops, clearing-out drops, and spring jacks, occupy the vertical portion of the frame in front of the operator. The desk, or horizontal portion, is partly occupied by a row of 10 pairs of plugs connected by flexible cords *C*, *C*, which are drawn through openings in the desk by the action of weights and pulleys *p*, *p*, in their respective loops. By this means the cords are kept out of the way of the

operator until required for use, the plugs only remaining above the surface of the desk.

It will be observed that the fourth pair of cords, counting from the left, is in use in the figure, the plugs being inserted in the jacks so as to connect together subscribers Nos. 5 and 78. Any one of these cords may be employed to make any connection between subscribers' lines, 10 being provided, so that 10 independent connections may exist at the same time.

In front of the row of plugs is a double row of 10 keys, employed for calling the attention of the subscribers from the switchboard, and in front of these is a single row of 10 keys employed for bringing the operator's telephone into circuit with any of the 10 cords; that is, in cir-

cuit with any of the pairs of subscribers with whom he may be connected by these cords. *M*, is the microphone transmitter supported in front of the operator to permit her to communicate with the subscribers, while a head telephone, not shown in the figure, is also connected by a flexible cord with the switchboard for the use of the operator.

Fig. 83, is a diagram of the connections normally existing between each subscriber and a central exchange. The connections of the subscriber at *X*, are the same as those shown in Fig. 68. *A A'*, is the line and *S*, is the isolated switchboard at the exchange. *J*, is the jack, and *D*, the subscriber's drop in the switchboard. As soon as the subscriber *X*, rotates his magneto hand generator, the current passes through the switch hook *K*,

through the line, *A A'*, the spring jack contact at *J*, and the drop *D*, completing its circuit through the ground. The

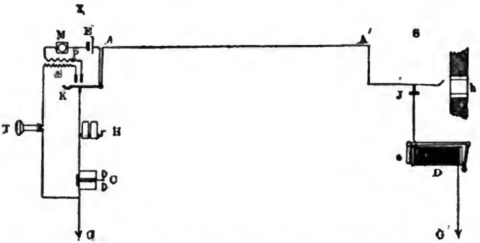

Fig. 83.—Diagram of Subscriber's Connection with Telephone Exchange on Ground-Return Circuit.

magnet *D*, attracts its armature *a*, thus releasing the shutter of the drop which falls and reveals the number of the subscriber.

The operator on seeing the drop fall inserts one of the cord plugs into the subscriber's jack *J*. This has the effect of

lifting the spring off the contact of the jack, and thereby opening the subscriber's circuit at this point, but re-establishing the circuit through the tip of the plug with the operator's telephone. The operator, on replacing the shutter, now inquires from the calling subscriber "What number?" The subscriber mentions the number of the subscriber to whom he desires to speak. The operator inserts the other plug of the cord in the jack of the subscriber desired, and calls up that subscriber with her generator. The two subscribers are then brought into immediate connection, except that the operator is able, at any time, to bridge her telephone between the connection and ground, to see if the conversation is being still carried on.

The above is shown diagrammatically in

Fig. 84, where the line from *X*, is connected directly through the cord of the central station with the line to *Y*, the clearing-out drop *D*, remaining in the cir-

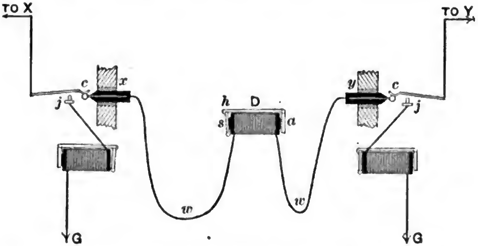

Fig. 84.—Diagram of Connection at Switchboard Between Two Subscribers Employing Ground-Return Circuit.

cuit. As soon as the conversation between *X* and *Y*, is over, they will ring off and release the shutter of the clearing-out drop. The telephonic currents employed in conversation are far too weak to operate the magnet of the clearing-out

drop, but the current produced by the magneto generator of the subscriber, who rings off, is amply sufficient to drop the shutter. When the clearing-out drop falls, the operator removes the cords, which, under the influence of the weights and pulley, fall through the opening in the desk until arrested by the plugs.

The connections of each pair of cords is shown in Fig. 85. P_1 and P_2, are the plugs, each connected respectively to the calling keys K_1 and K_2. When these keys are in the normal position, they rest against the upper contacts which are connected together through the magnet of the clearing-out drop. Consequently, when P_1 and P_2, connect two subscribers, they will be put in communication through the clearing-out drop D. The *listening key* K_3, is so arranged that when it is

pressed it makes contact and puts the telephone T, in bridge, or parallel circuit, between the line and ground through the secondary coil of the operator's in-

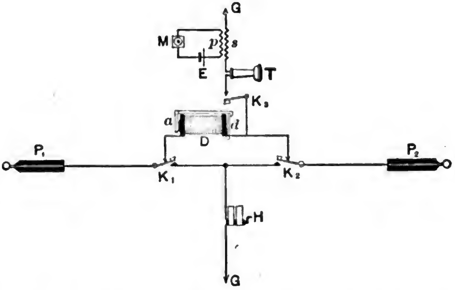

FIG. 85.—CONNECTIONS OF CORD AT SWITCHBOARD FOR GROUND-RETURN CIRCUITS.

duction coils. If the subscriber on the side P_1, is talking while P_2, is listening, all the current generated by the sound waves at the transmitter will pass through the cord of the clearing-out drop through the

receiving telephone connected with P_2; but, when the operator presses her listening key at K_3, a part of the current will be deflected and pass through her telephone T, the remainder passing through K_2 to P_2, as before. When the operator desires to call up either P_1 or P_2, she presses the key K_1, or K_2, and brings the magneto generator into operation, thus sending a calling current along that line.

We will now, with the aid of the drawings, describe exactly what takes place when a subscriber, say No. 55, desires to communicate with subscriber No. 83. His first operation (Fig. 67) is to call up the operator at the switchboard by turning the handle of his generator. This causes his drop, No. 55, to fall at the switchboard. The operator, if not already calling some other subscriber, replaces the shutter of

this drop, and inserts the plug of one cord into jack No. 55, at the same time pressing her listening key and inquiring "What number?" No. 55 replies, "83." The operator, if No. 83 is not already engaged, inserts the other plug of the same cord in jack 83, and depresses her ringing key on that side. She then turns her generator to call up No. 83. She listens with her listening key down, for 83 to reply. If 83 fails to reply, she rings up 83 again. When 83 replies, he is already in direct communication with 55 through the clearing-out drops. As soon as Nos. 55 and 83 have ended their conversation, No. 55 rings off, dropping the shutter and the clearing-out drop, and the operator withdraws the plugs from the board. It will be seen that the operator's magneto generator and telephone can serve any number of calling keys or listening

keys, since they are only used on one circuit at a time. The generator and the telephone are, therefore, in connection with the whole row of ringing keys and listening keys on the desk.

Another form of isolated-station switchboard is represented in Fig. 86. It differs from the one last described in various constructive and operative details. It is arranged for 100 subscribers. The face of the board *d*, *d*, has 10 rows of 10 drops each. Here the drop shutters are normally in a horizontal position, and fall to the vertical so as to cover the aperture above which they are set. Behind each shutter, is the aperture of the jack belonging to the subscriber. Consequently, the insertion of the plug into the jack lifts the shutter at the same time. This arrangement economizes space, since the jacks and

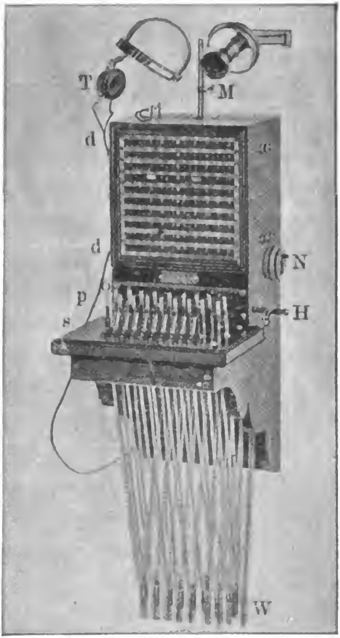

FIG. 86.—FORM OF ISOLATED-STATION SWITCHBOARD.

drops occupy the same portion of the board, each jack and drop occupying one square inch. The recess behind the shutter is concave, or funnel-shaped, so as to aid the plug in entering the jack.

Beneath the drops and jacks is a row of 10 clearing-out drops shown in Fig. 86 at *O*. These are connected between the plugs of each cord in the usual way. At *p*, is the row of 10 pairs of plugs united by flexible cords with pulley weights *W*. In front of these plugs is a row of 10 operating switches. Each operating switch has four positions.

(1) The switch is brought to the normal position, as shown in the figure, with the handle as far back as it will go.

(2) The switch is brought forward to the first white dot on the segment by its side. This introduces the operator's head

telephone *T*, and microphone *M*, into the circuit of the cord, in the same manner as shown in Fig. 84.

(3) The switch is brought forward to the second white dot on the segment. This brings the plug on the *calling* or *outgoing* side into connection with the generator, so that turning the handle *H*, calls the subscriber required.

(4) The switch is brought forward to the third dot on the segment, or as far forward as it will go. This brings the plug on the *connecting side* into connection with the generator, so that turning the handle *H*, calls the subscriber who has called up.

The series of operations with this switchboard is, therefore, as follows. Subscriber, say No. 78, turns his generator and thereby drops his shutter No. 78 on the switchboard. The operator inserts the

forward plug of any pair of cords into the hole covered by the shutter, thereby raising the same and causing the plug to enter the jack 78. She then brings forward the switch of that pair of cords to the first position and asks "What number?" Subscriber 78 gives the number he wishes, say 5. The operator takes the other plug of the same pair and inserts it in jack 5. She then brings forward the switch to the third point, and after turning her generator handle, moves the switch back to the second point, listening for the reply of 5. As soon as this has been obtained, she brings back the switch to the first point, thus cutting her telephone out of the circuit and leaving 78 and 5 interconnected through the clearing-out drop of the cords. As soon as 78 and 5 ring off, this clearing-out drop will release its shutter and the operator withdraws the

plugs from the jacks. If the subscribers fail to ring off, the operator will, probably, bring forward her switch to the second notch and listen for conversation or call "Are you through?"

N, is a *night-switch*, that is, a switch arranged so that when turned to the on position, any or all of the drops when they fall will ring a bell, and call the attention of the operator in case she should not be before the instrument. This is effected by allowing the metallic shutters to fall upon screw contacts, thus closing a local circuit through an electric bell. By turning this switch to the off position the bell is disconnected.

Fig. 87, shows the back of the switchboard of Fig. 86. *d*, *d*, are the backs of the 100 annunciator drops. The arma-

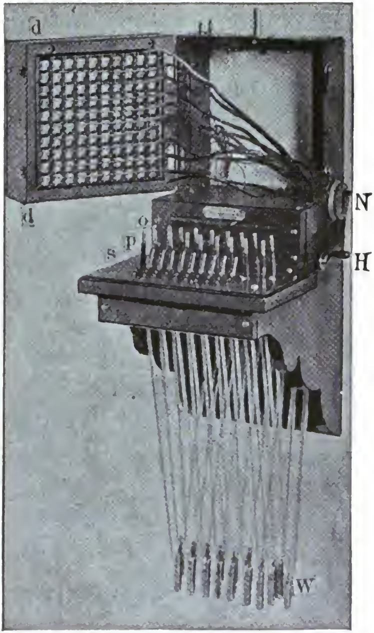

FIG. 87.—SWITCHBOARD OF FIG. 86 OPENED.

tures are here arranged by the side of the magnet and are pivoted about a vertical axis. The wires from the incoming cable are seen to be connected to their respective drops. In this case, one wire runs to each subscriber, a ground return being used for all.

Fig. 88, shows a similar form of switchboard arranged for 50 subscribers. This form of switchboard has a magneto transmitter instead of a microphone transmitter. Here there are 5 rows of 10 drops each. Nine of these drops are shown to have fallen. At *O*, there are 5 clearing-out drops, at *p*, 5 pairs of blocks and cords, while at *s*, are the operating switches. The first 3 switches on the left are at the first point, or in the cut-out-of-circuit position. The fourth switch is at the calling, or fourth position,

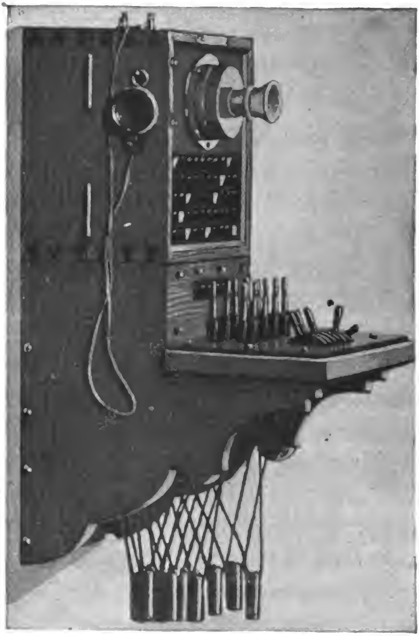

FIG. 88.—MAGNETO TRANSMITTER SWITCHBOARD FOR 50 DROPS.

while the fifth or last switch, on the right hand, is at the listening position. *M*, is a magneto transmitter, in which the magnet poles are extensions from the poles of the magneto generator. In front of them is a diaphragm of sheet iron. The distance between the poles and the diaphragm is capable of being regulated by turning the head *M*.

CHAPTER XI.

MULTIPLE SWITCHBOARDS.

When the subscribers connected with a switchboard exceed a certain number, say 200, their requirements usually transcend the capability of a single operator. It, therefore, becomes necessary to provide a switchboard of greater width so as to permit two operators, each with telephone transmitter keys, switches, and generators, to sit before it. These operators may occasionally have to reach across each other, in order to insert their plugs in the most distant jacks, but otherwise the arrangement is perfectly satisfactory. A switchboard of this type, in which no sub-

scriber has more than one jack, is called a *standard switchboard* whatever its dimensions may be.

When, however, the number of subscribers increases to say beyond 500, even this arrangement fails, because several operators are usually needed to attend to the subscribers, and the breadth of the switchboard exceeds the distance which may be conveniently bridged by a cord, when connecting two subscribers whose jacks are most distant from each other on the board. It, therefore, becomes necessary to introduce some modification. This may be carried out by two distinct methods.

One method consists in subdividing the switchboard into sections, each having auxiliary jacks, and interconnecting the

various sections, so that when a subscriber whose jack is, say No. 50, in section *A*, desires to be connected with a subscriber whose jack is No. 1010, in section *D*, the operator at *A*, connects *A*'s jack No. 50, to the auxiliary jack in connection with section *D*, and at the same time calls up operator *D*, and requests her to connect the corresponding jack in her section with subscriber 1010.

This method is illustrated diagrammatically in Fig. 89, which shows a *locally-interconnected switchboard.* At the upper part of the figure are indicated two sections of the switchboard and a line from a single subscriber in each. Subscriber No. 50 comes to section *A*, through a jack and drop to ground. The line from subscriber No. 1010, comes to section *D*, through a jack and drop to ground. The auxiliary jacks

d and *a*, are in electric connection between the sections *A* and *D*. In the lower part of the figure is shown the connection by a cord from jack 50, in section

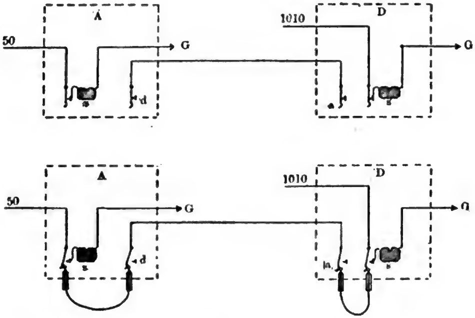

FIG. 89.—DIAGRAM OF LOCALLY INTERCONNECTED SWITCHBOARD FOR GROUND-RETURN CIRCUITS.

A, to jack *d*, while another cord connects jack *a*, in section *d*, to jack 1010.

The other method consists in reduplicating the entire board of jacks at inter-

vals, so that each operator can reach every subscriber with one of her cords. This method is called the *multiple switchboard method*, and a switchboard arranged for the applications of this method is a *multiple switchboard.*

A multiple switchboard is illustrated diagrammatically in Fig. 90, where, for the sake of simplicity, three subscribers' lines only are connected. It will be observed that in the upper part of the diagram line No. 50 enters panel *A*, at the first jack, and, after passing through the drop *d*, proceeds to the panel *B*, passing through the first jack—without a drop; it then proceeds to the first jack in panel *C*, also without a drop, and then to ground.

The line 250 follows a similar course through the three panels, except that its

drop is in panel *B;* while line 450, follows a similar course, except that its drop is in panel *C.* If subscriber 50, desires to

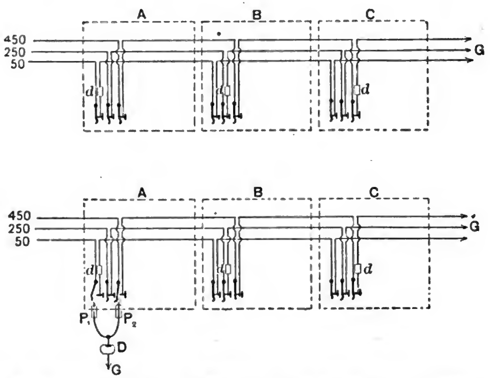

FIG. 90.—DIAGRAM OF MULTIPLE SWITCHBOARD USING GROUND-RETURN CIRCUIT.

be connected to subscriber 450, this is accomplished by the operator attending to 50, namely the operator at panel *A*, and she inserts a cord directly into the jack

450 of her panel. In a similar manner if subscriber 250, desires to be connected with 450, the connection would be performed by the operator at the panel where 250, has his drop; namely, in panel *B*.

In the lower part of Fig. 90, the connection is shown established between subscribers, 50 and 450, at panel *A*, plug P_1, being inserted as an answering plug in jack 50, and plug P_2, as the companion plug in jack 450. The clearing-out drop *D*, is left permanently in circuit between the junction of these plugs and ground. We have seen that the clearing-out drop is sometimes inserted in the main telephone circuit as in Figs. 84 and 85, but owing to the objectionable additional impedance thereby introduced, it has come to be regarded as preferable to employ the clearing-out drop as a high impedance

leak between the line and ground; or, in the case of metallic circuits, as a leak between the two line conductors.

It is evident that the advantage of the multiple switchboard is that the operator receiving a call can at once connect the calling subscriber with the subscriber desired, but this advantage is only gained by a great multiplicity of jacks. Each panel will have, say, 200 drops, or subscribers' lines, under immediate supervision, but must be provided with the jacks of all subscribers, even if these should amount in number to say 5,000. Consequently, to provide drops for all these subscribers there must be 25 panels, and $25 \times 5{,}000 = 125{,}000$ jacks in all. Each panel may, perhaps, be served by three operators, any one of whom can always reach any subscriber, either in her own

panel, or in the panel immediately adjoining.

The *locally-interconnected switchboard system* possesses the advantage of dispensing with the multiplicity of reduplicating jacks, but suffers under the disadvantage of necessitating both more time and labor to establish a connection, since two operators will, probably, be needed to establish a single connection.

All extended systems of telephony in commercial use to-day, are operated on one or both of these systems. In some cases the nature of the business conducted is such that the advantage is on the side of a local connection or *trunking* system; in other cases, a multiple switchboard is exclusively used; while in still other cases, a combination of a multiple switchboard and

a locally-interconnected switchboard is employed.

Fig. 90, represents a *panel* or *individual switchboard* forming one section of a *multiple central-station switchboard* capable of accommodating 3,000 subscribers in all. The upright frame is arranged to hold 5 compartments of 6 slabs each. Each slab holding 100 jacks, so that the entire panel contains 3,000 jacks, when filled completely, only 400 of which are shown in the figure. These jacks are numbered consecutively from 1 to 3,000. Of the 3,000 subscribers, thus accommodated, only 200 are in direct communication with the section, say Nos. 1 to 200. These have their annunciator drops in the frame *D D*. All the calls coming from these 200 subscribers can be handled by one operator during comparatively idle

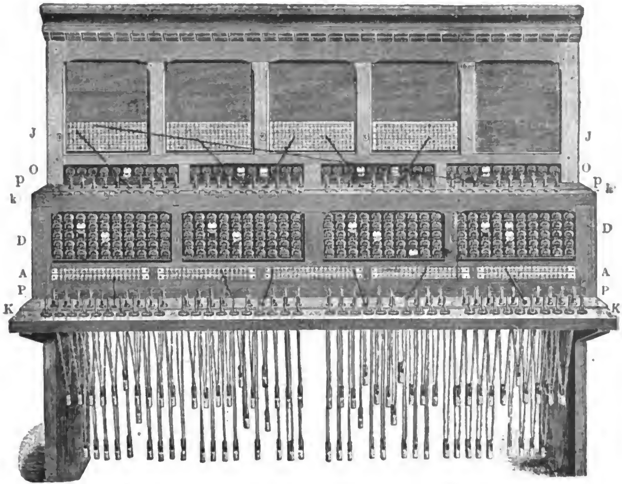

FIG. 91.—PANEL OF CENTRAL-STATION SWITCHBOARD.

hours, by two operators during busier hours; and, perhaps, by three operators during exceedingly busy hours. The jacks corresponding to the 200 subscribers directly under the charge of the operator, appear not only in the main panel, as they do through the various consecutive panels, but also in a separate row *A A*, and are called *answering jacks.* It is, of course, not absolutely necessary to have these 200 jacks duplicated in the same panel but it is usually much more convenient to have them immediately before the operator, instead of, perhaps, half-way up the board. *P*, *P*, is a row of 40 answering plugs for insertion into the answering jacks, while 40 other companion plugs, corresponding to those beneath, are arranged in the row *p p*, to be inserted into any of the 3,000 jacks in the upper frame.

When subscriber 180, desires to communicate with, say, subscriber 2,510, he turns his generator handle thereby sending a slowly alternating but powerful current along his line, which entering the annunciator magnet in this panel releases shutter No. 180. The operator inserts an answering plug from the row *P P*, into answering jack No. 180, and, on learning that No. 2,510 is needed, takes the corresponding plug from the upper row *p p*, and inserts it in jack No. 2,510. She then depresses the ringing key in the line *k k*, corresponding to this cord, thereby calling the attention of the subscriber 2,510. Having established communication between the subscribers, the listening key on the line, *k k*, is released, and her attention may be given to other calls. The clearing-out drop of each cord is situated in the row *OO*. It will be observed that every one

of the five connections established in the board, has its answering drop released, showing that the operator may disconnect them, while there are 10 new calls announced in the annunciator drops in the frame *D D*, which the operator has yet to attend to.

Subscribers Nos. 201 to 400, will be similarly dealt with in the next panel, placed by the side of the panel shown in Fig. 91. Nos. 401 to 600 will be dealt with in the third panel, and Nos. 2,801 to 3,000, in the fifteenth panel. Consequently, when the switchboard is completely filled by 3,000 subscribers, there will be 15 of these panels placed side by side each having 3,000 *multiple jacks*, and 200 *answering jacks*, making a total of 48,000 jacks in use. Besides these there will be additional jacks for other purposes.

Since the total number of jacks required in a multiple switchboard, evidently increases, approximately, as the square of the number of subscribers, the expense of

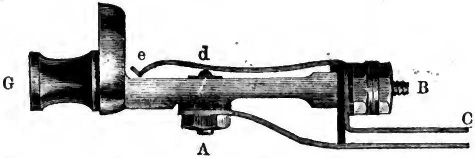

FIG. 92.—SIDE VIEW OF A SINGLE JACK IN MULTIPLE SWITCHBOARD.

installing a multiple-switchboard central exchange increases more rapidly than the number of subscribers.

Fig. 92, shows a single spring jack removed from the board. It consists electrically of three metallic parts *A*, *B* and *C*. *A*, is a screw, tipped at *d*, insulated from the mass of the jack, and electrically connected by the metal strip shown with the

corresponding jacks in the successive panels. $C_{,}$ is a gun metal strip, bent as shown, and resting normally in contact with the tip of the screw A, at the point d. $B_{,}$ is the brass mass of the jack whose opening is at G.

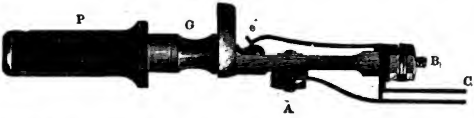

FIG. 93.—SIDE VIEW OF A SINGLE JACK IN MULTIPLE SWITCHBOARD WITH PLUG, *P*, INSERTED.

Under normal conditions, therefore, electric connection exists between A and $C_{,}$ through the contact d, while $B_{,}$ remains insulated from both.

Fig. 93, represents the effect of inserting a plug into the jack. It will be observed that the spring $C_{,}$ is lifted out of contact with the screw A, but makes contact with the tip of the plug at *e*. At the same time,

the shank of the plug *P*, is brought into separate connection with the mass of the jack through the metal sleeve *G*, thus establishing another contact between the

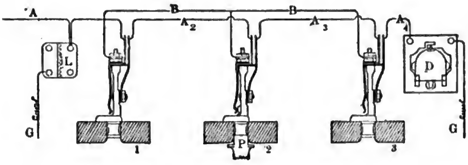

FIG. 94.—DIAGRAM OF MULTIPLE-SWITCHBOARD CONNECTIONS.

shank of the plug and *B*. The function of this contact will be presently described.

Fig. 94, represents the connections of a single line with ground-return circuit entering a multiple board. The three jacks shown at 1, 2 and 3, represent three successive panels of a multiple switch-

board. The line enters at the left hand side at A, passes through the lightning arrester L, through the contact of the first jack in the first panel No. 1, along the connecting line A_2, between panels 1 and 2, and, instead of passing through the second jack, is connected to the plug P, which will itself be in connection either with some other subscriber's line, or with the telephone apparatus of the operator. On withdrawing the plug from jack No. 2, the line circuit will continue through A_3, the jack of panel 3, and the drop D, to ground. Jack No. 3, will, therefore, probably, be the answering jack of this particular subscriber, being situated next to his drop. A plug will, therefore, be inserted in jack No. 3, every time that the subscriber on this line calls up the operator, and plugs will only be inserted in jacks, 1 and 2, when the subscribers whose answering jacks are

in panels 1 and 2, desire to communicate with *A*.

If, while the plug remains inserted in jack No. 2, some subscriber of panel No. 1, calls for connection with subscriber *A*, it is necessary that the operator at panel No. 1, shall know that line *A*, is already engaged, since it would not be probable that operator No. 1, could see the plug *P*, in the distant panel. For this purpose a special wire *B B*, runs between the successive panels, connecting all the jacks of this number together. The shank of the plug *P*, is insulated from the tip and is connected with a voltaic battery.

The use of the additional, or "*test wire*," *B B*, may be understood from an examination of Fig. 95, which shows two subscribers' lines, Nos. 210 and 1,560, passing

through two panels on their way to ground. No. 210, is connected at the left-hand panel by a cord direct to jack 1,560, for conversa-

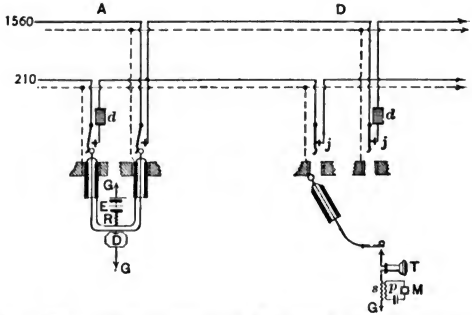

FIG. 95.—"BUSY" TEST OF MULTIPLE SWITCHBOARD.

tion. It will be seen that the two plugs have each two wires in them, one connected with the tip, and the other connected with the shank. The tips are in contact with the phosphor bronze springs of the jacks, while the shanks are in contact with the external rings in front of the jacks.

A voltaic battery is connected to ground from the shanks of these plugs through a suitable resistance coil *R*. This has the effect of connecting all the rings of the corresponding jacks in every panel with a battery to ground. In other words, the rings of Nos. 210 and 1,560, are connected with a battery in every panel by the insertion of the two plugs in a single panel.

Should some subscriber at the right hand panel ask for connection with subscriber 210, the operator at this panel will touch with the tip of one of her cord plugs, the ring of jack No. 210, as shown in the figure, while depressing the listening key. She will thereby permit a continuous current to flow from the battery *E*, through the ring of 210, in panel *A*, to test wire 210, behind the switchboard to the ring 210, in panel *B*, the tip of her plug, its cord,

her telephone and ground. This continuous current will produce a sharp click in her telephone, which will indicate that the plug is inserted in jack 210 of some panel, and she will immediately inform the subscriber communicating with her that 210 is "busy."

If this *busy test* were not provided on a multiple switchboard, the whole system would be practically inoperative. With a single-standard or isolated-station switchboard, it is possible for the operator or operators to see at a glance whether the single jack belonging to each subscriber is occupied or not by a plug, but in a multiple board, which may be 250 feet long, it is absolutely impossible for the operator at one section to know whether a plug may not be already inserted in some jack corresponding to the number of the sub-

scriber she wishes to put in communication. By means of this test any operator can tell in a second or two, whether any subscriber out of, perhaps, 5,000 in connection with a multiple switchboard, is busy or not, and merely by touching a jack within cord length of her position. It is evident, however, that the number of wires behind a multiple switchboard has to be doubled in order to provide this test.

Fig. 96, shows an elevation and section of a multiple switchboard. *C*, *C*, *C*, are the jack boards behind which are the wires connected to them, and which are packed away neatly in oval-shaped cables. *P*, are the cord plugs, each carrying two wires, one connected with the tip, and the other with the shank, as already explained. *D*, *D*, are the annunciator drops

of the subscribers, controlled by the panel. *r*, are the ringing keys and *S*, the listening switches.

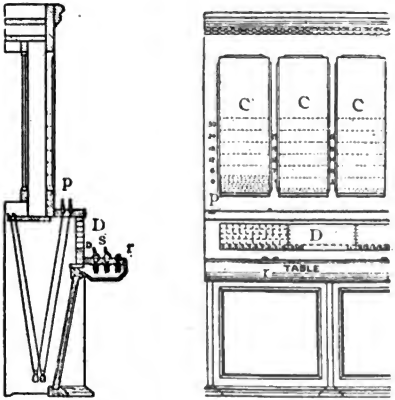

FIG. 96.—ELEVATION AND SECTION OF MULTIPLE SWITCHBOARD.

Great ingenuity has been displayed in effecting economy in the space occupied by the jacks. A compact form is repre-

sented in longitudinal section in Fig. 97. Here *o*, is the opening on the face of the board, *r*, the tube which makes contact with the shank of the inserted plug. *w*, is the screw, normally in contact with the

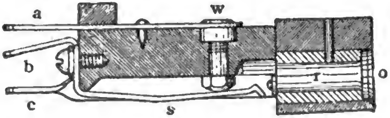

FIG. 97.—LONGITUDINAL SECTION OF A FORM OF JACK.

spring *s*. *a*, *b* and *c*, are the terminals of the screw, spring and tube. Four of these jacks can be set in a space of one square inch on the face of the switchboard. Fig. 98, shows a form of plug suitable for insertion in such a jack. *S*, is the shank and *T*, the tip of the plug, which are insulated from each other. *w*, is a screw in the interior for clamping the wire leading

to the tip. These wires enter from the interior.

Fig. 99, represents a form of annunciator drop. This is made from a rod of

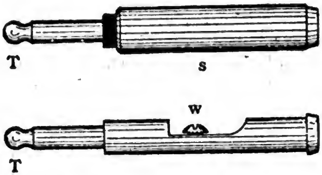

FIG. 98.—FORM OF PLUG FOR JACK.

soft iron turned out to the right dimensions, and with a core of soft iron and a magnetizing coil *M*, inserted in the interior. The face *P*, projects from the surface of the switchboard. The end *A*, is open and is faced by the soft iron armature or cover *A*. When an electric current passes through the magnetizing

coil *M*, the magnet attracts the armature *A*, which moves on a horizontal axis through the line of pivots *C*, and thereby raises the arm *D*, which is furnished with a hook *C′*, upon its extremity. As soon as

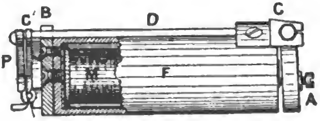

Fig. 99.—Tubular Annunciator Drop.

this hook is lifted, the shutter *P*, falls by gravitation and reveals the number of the drop upon the face it covered. It is found necessary to make these magnets *iron-clad; i. e.*, encased in complete cylinders of iron, in order to prevent magnetic disturbance from one annunciator magnet to the one adjoining it, and producing what is called "*cross-talk*" in a

manner which will be subsequently described.

The general appearance of a portion of a multiple switchboard is represented in Fig. 100. This switchboard is intended to connect 5,400 subscribers. Here the operator's microphones are suspended by cords from the shelf of the board, and the head telephones are connected by flexible cords, one to each microphone.

Multiple switchboards have been designed to accommodate as many as 10,000 subscribers, although the greatest number of subscribers actually wired to a switchboard is about 6,000.

The spectacle presented by a large central-telephone exchange employing a multiple switchboard is a most interest-

FIG. 100.—VIEW OF A MULTIPLE SWITCHBOARD.

ing one. A long row of vertical panels is seen, covered with drops, jacks, and cords, and a long row of operators seated

before these panels, each operator constantly whispering into the transmitter suspended before her face. Although during the busy hours of the day, probably, nearly all the operators are talking at the same time, yet so low is the tone of their voices, that but little sound fills the room and the click of the apparatus is distinctly audible.

The rate at which calls come into a switchboard, that is, are received at a central station, varies with the time of day. The busiest hour of the day is usually about 10 A. M. Fig. 101, shows a heavy black curve representing the number of calls received from subscribers at a switchboard in a large telephone station, at different hours of the day. Up to 7 A. M. the number of calls is less than 100 per hour. At 8 A. M. the number com-

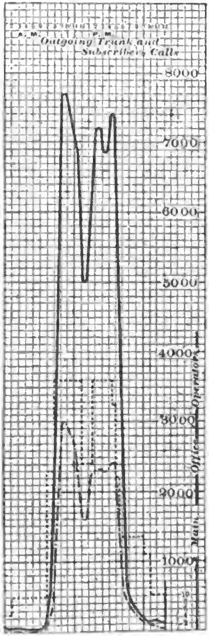

FIG. 101.—DIAGRAM OF NUMBER OF CALLS PER HOUR AND NUMBER OF OPERATORS IN ATTENDANCE AT VARIOUS HOURS OF THE DAY IN A PARTICULAR CENTRAL STATION.

mences rapidly to increase, and between 9 and 10 it is at the rate of 7,700 per hour; or at the rate of nearly 130 a minute, more than 2 a second. This is the busiest hour. About lunch time, the rate of calling slackens to 5,000 per hour, rising again in the afternoon to 7,200 between 2 and 3 P. M. There is a final peak of the curve, about four or five o'clock before business closes for the day in the offices. After five o'clock, the rate of calls falls off as rapidly as it grew. The broken curve indicates the number of calls that were trunked out from this station. It will be seen that about one call in three was trunked out, by connecting the subscriber to a line running to some other station and requesting that station to connect this line with the subscriber desired. The number of operators is shown by the dotted curve to have been 72 during

the busy time of day, reducing to 5 at midnight.

In New York City there are twelve central-station telephone exchanges, extending from Broad Street into Harlem, adjoining stations being about one mile apart. At each of these stations is a multiple switchboard, so that any subscriber desiring to speak with any other subscriber in the same district, is immediately put into communication with that subscriber at the same switchboard. When, however, a subscriber is in another district, the call has to be trunked out to the nearest station, and the connection effected at both switchboards simultaneously. The average distance covered by a New York telephone call is, approximately, three miles, the longest being fifteen miles in the New York system. Each day disposes of

150,000 telephone calls in this New York system, about 20 per cent. of which fail to produce immediate connection, owing to the fact that the subscriber desired is busy, so that about 120,000 conversations are effected daily by means of the New York telephone system.

We have hitherto considered the connections on multiple switchboards as though all the subscribers employed a ground return. As a matter of fact, however, practice is gradually eliminating the use of the ground return from commercial telephony, owing to the great number of inconveniences to which a ground-return system is exposed. The connections which are necessary in a multiple switchboard, either for a *metallic-circuit system*, or for a system which is partly metallic circuit and partly ground return, as it

usually exists in practice, do not differ in principle from those already indicated, but are considerably more intricate in detail. The "test" wire is made to serve as the return conductor.

Notwithstanding the great complexity of a large multiple switchboard, it is, nevertheless, the most effective means of dealing with the telephone exchange problem that has yet been devised. It possesses one marked disadvantage, and that is the great number of contacts through which each line circuit must necessarily pass in series. For example, we have seen that a board for 5,400 subscribers, when completely equipped, may possess 30 panels and each line must pass through 30 spring-jack contacts in succession, one in each panel. The presence of a small quantity of dust or oxide, at any

of these contacts, may introduce so high a resistance in the circuit as practically to disable that line, so that the introduction of large multiple switchboards not only introduces complexity and expense in material, but also increases the liability to accidental disablement. For this reason a switchboard has lately been introduced, called the *three-wire board* or *branch-terminal board*, designed to obviate this difficulty. In this board the jacks for any one subscriber in the successive panels, instead of being connected in series, are connected in parallel.

The connections of a three-wire switchboard are shown diagrammatically for a single circuit in Fig. 102. Here *A* and *B*, are the two wires forming either the ends of the metallic circuit from a single subscriber, or the ends of wires leading to the

subscriber and to ground respectively. These two wires run the entire length of the switchboard and are tapped at each panel to one jack. The *B*-wire is tapped

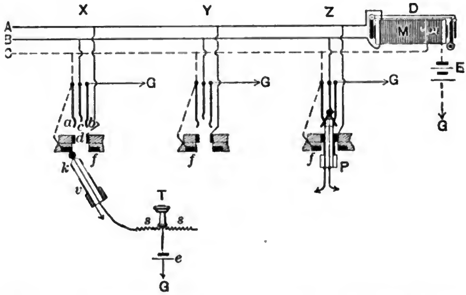

FIG. 102.—DIAGRAM OF BRANCHING OR THREE-WIRE SWITCHBOARD.

to a spring *c*, and the *A*-wire is tapped to a ring *d*. The third wire *C*, is indicated by dotted lines, and is the test wire by which the operator is enabled to ascertain whether the line is busy at some other panel. This

wire is also connected by taps both to the spring *a*, and to a ring *f*. The lines *A* and *B*, terminate in the coil *M* of the annunciator drop. This drop instead of requiring to be restored by hand, is self-restoring, and is called a *self-restoring drop*.

The insertion of a plug, as at *Z*, connects the two wires of the plug cord to the lines *A* and *B*, by the shank and tip of the plug respectively. At the same time an insulated metallic collar, near the tip of the plug, bridges across the springs *a* and *b*, thus grounding the external ring *f*, of the jack and the test wire *C*, running between all the jacks of that subscriber.

The grounding of the test wire serves two purposes. In the first place it completes the circuit of a local voltaic battery

E, through the local coil *m*, of the drop and ground. The current in this circuit automatically restores the drop shutter, and keeps it locked at the restored position as long as the plug *P*, remains inserted. In the second place, the grounding of the test wire, grounds all the external rings *f*, *f*, *f*, connected thereto, and enables any operator to ascertain that the line of this subscriber is "busy" at some panel. This "busy" test is indicated at panel *X*, where the tip of the plug, connected through the listening key with the operator's head telephone *T*, and voltaic battery *e*, completes a circuit through the test wire *C*, and the ground connection in the collar of plug *P*, thus notifying the operator *X*, by the click, that the line is occupied. The telephone in this case has its coil divided into two portions and a ground connection established at the centre.

Fig. 103, shows a plug and jack designed for use in a three-wire board. T, is the external or test ring designed to make contact with the tip of the plug in

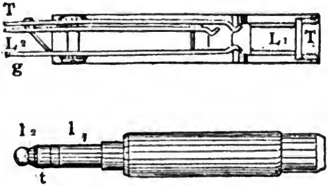

FIG. 103.—JACK AND PLUG OF THREE-WIRE SWITCHBOARD.

making the "busy" test. L_1, is the ring connected with one line, which makes contact with the shank of the plug at l_1. L_2, is a spring which is connected to the other line and makes contact with the tip of the plug l_2. T, is the spring connected to the test line for this subscriber, and making contact through the insulated

collar *t*, of the plug with the grounded spring *g*. This jack, therefore, employs three springs and two rings. The advantage of the system is that the subscriber's line avoids all contacts except at the jack when interconnection is effected.

The form of drop employed in the three-wire board is an improvement over the original form. Not only is time required to restore a drop that has fallen, but a drop will sometimes cause inconvenience by falling accidentally during conversation. The drop represented in Fig. 104, is a *self-restoring* and *self-locking drop*. That is to say it is automatically restored by the insertion of a plug in the calling subscriber's answering jack, as already described, and is, moreover, automatically locked, and so prevented from falling, during the continuation of the con-

versation, by a continuous current passing through the winding *m*, in the drop from a battery, through the collar of the plug inserted in the subscriber's jack.

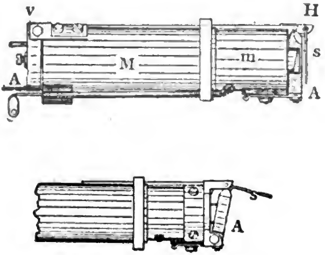

Fig. 104.—Self-Restoring Drop.

The magnet of this drop is in two parts *M* and *m*. The winding *M*, is connected across the line, while the winding *m*, is connected to the test wire as shown in Fig. 102. When the subscriber calls the central station, the magnet *M*, is excited by an alternating current from his gener-

ator, and attracts its armature *A*, which, being pivoted at *A*, raises the hook *H*, and permits the heavy armature *A*, pivoted at its lower edge, to fall away from the magnet, thereby pressing forward the shutter *S*, into the position shown below. The number of the drop upon the face of the armature *A* is then revealed to the operator. As soon as the operator inserts a cord plug in the answering jack of this subscriber, a continuous current passes from a local battery through the winding *m*. This attracts the armature *A*, restoring the shutter *s*, and locking it beneath the hook *H*. It also holds it attracted during the time that the plug remains inserted. When the plug is removed, the current is cut off the winding *m*, so that any other call on this line will again cause the shutter to fall. Another advantage incident to this form of drop is

that it can be protected by a glass cover and set out of reach of the operator. The space thus gained being available for additional jacks.

The problem of designing a telephone switchboard is necessarily a difficult undertaking, for the reason that when the first panel is in place, all the rest of the switchboard must practically conform with it, and a policy has to be adopted at the outset, which can only be altered at great expense. If the business of the exchange is principally local, a multiple switchboard is the most suitable. If, on the other hand, the business is largely long-distance or general, a trunking-out board is necessary; but in all cases some trunking out is necessary, even with a multiple board, and some local interconnection is necessary even with a trunking-out business. Fig.

105, shows an operating room in which the switchboard on the right-hand side is for answering of trunking-out calls, while the

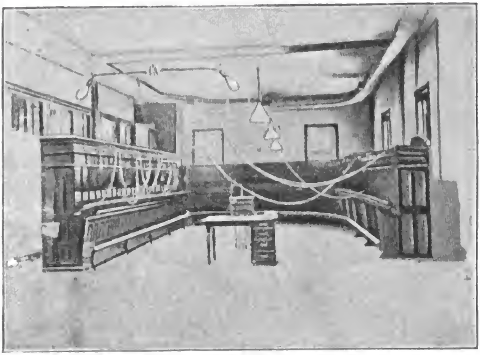

FIG. 105.—VIEW OF OPERATING ROOM.

switchboard on the left-hand side is a multiple switchboard for local interconnection.

Near the centre of the room is the chief operator's desk arranged so that the chief operator can communicate by telephone

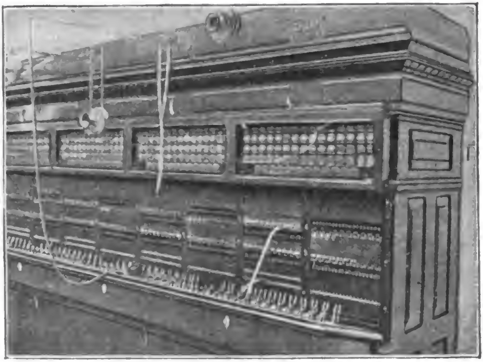

FIG. 106—VIEW OF TRUNKING-OUT SWITCHBOARD.

with any operator in the room. For this purpose a simple switchboard is provided at this desk. Fig. 106, gives a view in greater detail of the board on the right-hand side of Fig. 105. In the upper part

of the board is a row *D*, of subscribers' drops, arranged on the three-wire system, self-restoring, and protected from dust by being placed behind a glass cover. Immediately above the desk, with its row of keys and switches, is a line of answering jacks corresponding to these drops, one to each subscriber, thereby allowing about 70 subscribers to each desk. Above the answering jacks are rows of trunk-line jacks, some of which run to other stations and some to other operators in the same station at the multiple switchboard on the opposite side of the room.

Fig. 107, represents the multiple switchboard on the left-hand side of the room. It differs from an ordinary multiple switchboard in being unprovided with drops, since the instructions are received by each operator, from some operator on

the right-hand side, and communicating with the subscriber to be connected. Thus, an operator on the left-hand side is

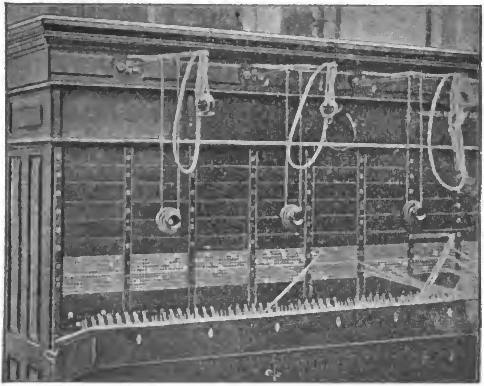

FIG. 107.—MULTIPLE SWITCHBOARD.

called by an operator on the right-hand side, and is instructed to connect No. 253 with No. 896. This is accomplished by means of a connecting cord.

It will be observed in this figure that the jacks are interspersed with small white shutters. These are visual signals, which are sometimes used, in place of a test-ring, to indicate when a line is busy. A small electromagnet, situated at each jack, drops a shutter over the jack as soon as a plug is inserted into any jack of that number on the other panels of the switchboard.

CHAPTER XII.

TELEPHONIC CIRCUITS.

It may be interesting to consider the manner in which telephonic currents, as well, indeed, as all electric currents, are propagated along conducting wires. The popular idea of an electric current is the flow of something through the mass of the conducting wire. In other words, the wire, regarded as a conductor, is looked on as a pipe through which a fluid; *i. e.*, the electric fluid, is supposed to flow, none of the electric fluid passing through the non-conducting medium outside the conductor. While this idea serves as a convenient basis on which to form working ideas

concerning the propagation of an electric current, yet in point of fact, the electric current is not propagated through the conductor, but through the non-conducting medium; *i. e.*, the ether which surrounds the conductor. The true statement, perhaps, is that the electric current does not flow through the wire, but through the medium surrounding it, the wire simply serving as a guide to determine the direction in which the current will flow.

To a person watching the progress of a summer shower over the surface of the earth, it would be evident that the real propagation of the storm through the air takes place in a direction generally along the surface of the ground, or parallel thereto. Such an observer could see the precipitation of rain upon the surface, accompanying the storm. To a mole living

below the surface of the ground, and, therefore, unable to perceive the storm, it would appear to be propagated through the ground, since the moisture would be felt to travel along in the direction of the storm at a definite rate.

Could the human eye detect the ether and its disturbances, the propagation of an electric current would, in all probability, appear as a disturbance in the ether propagated along the wire forming the circuit, and accompanied by an absorption of energy into the substance of the wire in the form of heat. In other words, the electric current is, in reality, propagated through the ether surrounding the wire; and what is found within the wire is a frictional exchange of electric energy into heat.

Let us suppose that at the station, *A*,

Fig. 108, a steady E. M. F. exists, as for example by the use of a voltaic battery *E*. The two ends of the battery are connected respectively to two comparatively short,

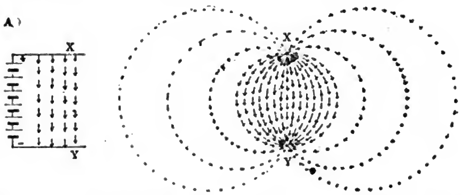

FIG. 108.—DIAGRAM OF DISTRIBUTION OF ELECTRIC FLUX BETWEEN TWO PARALLEL OPEN-CIRCUITED WIRES.

parallel wires *X* and *Y*, forming the terminals. There will be produced around this battery, and also between the terminal wires, an electric disturbance in the ether, even though the wires are disconnected, and no permanent electric current can flow. This disturbance is invisible to the eye, and can only be detected by sensitive elec-

tric instruments. It constitutes what is generally known as an *electric charge.* Regarding the wires lengthwise, as on the left-hand side of the figure, the electric flux through the ether flows in planes perpendicular to the wires, in a direction which is assumed to be from the positive wire X, to the negative wire Y, except round the battery, and at the ends of the wires, where the distribution of flux is more complex. Regarding the wires endwise, as on the right-hand side of the figure, the electric flux streams from the positive to the negative wire in curves which are all arcs of circles for the particular case considered. It is assumed that there is neither a flow of matter between the charged wires, nor a flow of ether, but that there is the maintenance of a stress in the ether along these lines. In other words, the ether is strained between the charged

wires along the curves indicated. This state of things will exist as long as the E. M. F. is maintained in connection with the wires, and no energy will be required to maintain it.

If now the battery wires are connected to two parallel, insulated conductors, suspended upon poles, as in the case of an ordinary pair of telephone wires, the electric flux immediately rushes outwards from the battery along the surface of these wires and permeates the entire ether space between them, even though their circuit remains open at the distant end. In Fig. 109, the electric flux is represented as commencing to move sideways from the battery in the direction indicated by the large arrow. The velocity with which this motion takes place is the velocity of light in air. The passage of an electric flux

over the surface of the wire constitutes what is called an electric current, and is accompanied by two distinct phenomena; first, the production of a magnetic flux around the conductors having a direction at right angles to the electric flux;

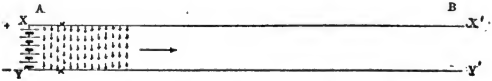

FIG. 109.—ELECTRIC FLUX MOVING OVER PARALLEL WIRES TOWARDS THE DISTANT END OF A CIRCUIT.

and, second the absorption of the electric flux and its attenuation as it proceeds by reason of the imperfect conduction, or electric resistance, of the conductor. Under certain conditions the rate of absorption of the travelling electric flux will be so great that, although its velocity is that of light, yet its disappearance into the conductor, absorbed as though by a sponge, retards very materially the arrival of the flux at

the distant end, so that the apparent velocity of the flux, including the effects of absorption, is very much less than the velocity of light.

If the distant ends X^1 and Y^1, Fig. 109, remain open, the effect of connecting the wires of the battery will have been to produce a sudden rush of electric flux over the surfaces of the wires from A to B, representing a sudden electric charge of the system, and a brief electric current. On the arrival at the electric flux at B, there will be a reflection of the motion like the reflection of a pulse in a string fastened to a support and shaken at the other end. The reflected wave, if not completely absorbed, will be again reflected on reaching A. These currents, during their existence, will be accompanied by magnetic flux enveloping the wires, but the magnetic flux disap-

pears as soon as the electric flux becomes stationary, and the wires are fully charged to the pressure of the battery. The system then behaves as does the system of Fig. 108, except that now the wires connected to the battery are much more extended.

If the distant ends of the conductors at *B*, instead of being left insulated, are connected together, so as to form a closed circuit, the electric flux, on reaching *B*, instead of being reflected, continues to move around the circuit, and, therefore, travels back to *A*, but with the direction of the flux between the wires reversed, as is represented in Fig. 110, where the heavy arrows, pointing downwards, indicate the direction of the flux leaving the battery, while the light arrows, pointing upwards, represent the direction of the flux return-

ing to the battery, after having turned the corner at *B*. On reaching the battery, it again turns the corner following the path of the battery, moving from *A* to *B*, as in-

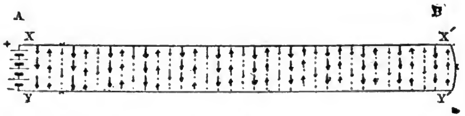

FIG. 110.—ELECTRIC FLUX MOVING OVER THE CONDUCTORS OF A CLOSED METALLIC CIRCUIT.

dicated by the faint arrows, pointing downwards.

In this way a succession of reversed pulses is set up, moving in opposite directions between *A* and *B*, and attenuating as they run, while at the same time fresh flux is steadily poured out from the source at *A*. Since the direction of the current produced by a moving electric flux de-

pends, both on its direction of motion, and on the direction of the flux, it will be evident that the current produced by a downwardly pointing flux, moving from right to left, is the same as an upwardly pointing flux, moving from left to right. Consequently, the current in the circuit is not reversed, but increases at any point by the reversion of a pulse, and, in spite of attenuation, the total effect after the steady state has been reached, in a circuit without leakage, is to produce the same current strength in all parts of the circuit, the reversed waves at *B*, making up by their greater intensity for the attenuation which is taking place in the passage from *A* to *B*. In other words, the total rate of travel of electric flux over the circuit, taking both direction of motion and direction of flux into account, is the same over all portions.

It is a universal law that electric flux, no matter how produced, when moving through space at right angles to its own direction, develops magnetic flux in a direction at right angles both to the electric flux and to its motion. The intensity of the force producing the magnetic flux, called the *magnetic force*, is proportional to both the velocity of the electric flux and its intensity; or, in other words, is proportional to their product. In Fig. 110, the electric flux has everywhere the same velocity after the steady state has been acquired when the reflected pulses are summed. Consequently, since the speed of the electric flux is the speed of light in the medium through which the flux is travelling, the magnetic force at any point near the wire is simply the product of the electric flux at that point, and the light speed at which it is moving. The nearer

we come to one of the wires, the more powerful the magnetic force becomes, since the more dense will be the electric flux which rests upon the surface of the conductor. The magnetic force is a maximum, immediately at the surface of each conductor, because the electric flux, which is rushing past the surface at this point, has its maximum density there.

When the wires connecting *A* and *B* are thin and long, the current established in the circuit according to Ohm's law is feeble, because the flux is rapidly absorbed, and only one or two reflected pulses of any appreciable magnitude can occur before practical extinction. On the other hand, if the conductor had no resistance, an infinite current strength could be established because an infinite number of unabsorbed pulses could co-exist in the

circuit, although a correspondingly increased time would be required to establish the steady state, as the pulses would be continually accumulating and adding their effect to the stream of electric flux leaving the battery.

According to this hypothesis, therefore, an electromotive source is a means for developing electric flux. If the source be insulated, the production of the electric flux will cease as soon as the ends or terminals of the source are charged. If a conductor is brought into contact with an extremity or terminal, the flux will immediately spread laterally over the surface of the added conductor, and will continue to flow for a brief interval, depending upon the "capacity" of that conductor. This charge, or rush of electric flux, constitutes a brief current, and the source will have

been called upon to develop this extra quantity of flux at the expense of some contained energy, which is chemical in the case of a voltaic battery, and mechanical in the case of a dynamo. Finally, if the terminals of the source are connected through a complete conducting path, a steady stream of electric flux is given off from the source accompanied by rapid reversal of flux streams at each end of the circuit. The function of the conductor is to lead the flux through the ether. The flux rests upon the conductor and is not absorbed while it is at rest, but when gliding along the surface of the conductor it becomes absorbed as it runs, and gives up its energy to the conductor as heat.

Fig. 111, is the corresponding diagram for the effect produced in a ground-return circuit. $X X$ is the wire, supposed to be

now supported on poles; while G, G, is the ground assumed to be level and of good conducting material. As soon as connection is made to the battery, or source E, the electric flux, which was bound to the

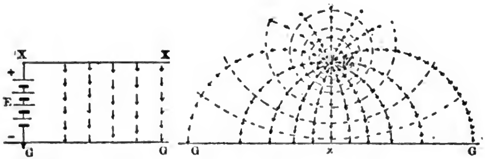

FIG. 111.—ELECTRIC FLUX MOVING OVER THE SURFACE OF A CLOSED GROUND-RETURN CIRCUIT.

terminals of the source and could not escape from them, is now given free play over the surface of the wire XX. It rushes along this wire, having the direction of the arrows pointing downwards, until it reaches the grounded terminal at the distant end. Here it undergoes reversal, turning the corner of the circuit as already

described, so that the returning pulse points upward. The continued succession of pulses will occur until the steady state is reached, the current being the sum of all the direct and reversed waves of flux added together. The current waves all add together, while the E. M. F. of the reversed waves is always opposite to the E. M. F. of the direct waves, so that the pressure or E. M. F. is less at the distant end, being zero when directly grounded, and a maximum at *X*, being there almost the E. M. F. of the battery. The flux paths differ in this case from those which are produced between the wires of the metallic circuits as shown in Fig. 110. They are indicated on the right-hand side of the figure diagrammatically. The arrows indicating the distribution of the electric flux, and the dotted lines, the distribution of magnetic flux around the wire

produced by the motion of the electric flux. The flux is, therefore, distributed in planes at right angles to the wire, and this distribution is steadily maintained as the flux moves sideways along the wire. As the flux moves it produces magnetic force everywhere at right angles to it, and the path of the magnetic flux lines will, in its vicinity, be practically circles surrounding the wire.

In practice a circuit is never immediately grounded or short-circuited at the distant end, but is always completed through some electro-receptive device, such as a motor, lamp or electromagnet. In the case of an electromagnet, the electric flux, as it rushes around the circuit, is crowded into a comparatively small space and acquires great density. The corresponding magnetic force produced in the air or ether around it is also great, and is,

moreover, multiplied by the number of turns of conductor. Consequently, the total magnetic force which is produced in the conductor may be very considerable, and is further greatly enhanced by the presence of the iron core. The total work that the circuit is capable of producing at the distant end, depends upon the total magnetic flux that can be developed, in this manner, by the stream of rushing electric flux, and the mechanical energy which the magnet can produce as in an electric motor, depends entirely upon the amount of energy which can be developed in magnetic form in the surrounding ether. An electromagnet, or an electromagnetic motor, is a device for transforming this locally generated magnetic flux into mechanical energy.

Regarded from this latter point of view,

an electric circuit, telephonic or otherwise, is a device for projecting electric flux in a definite direction, and causing the streams to be contracted and intensified at the receiving end of the line so as to collect a large amount of energy at that spot.

We have hitherto considered the effect produced by a continuous E. M. F. impressed upon a circuit. When an alternating E. M. F. is impressed upon a circuit the effects do not differ in their nature, but are simply the result of periodically reversing, at definite intervals, the E. M. F. applied. At each reversal the entire flux distribution is reversed. This requires a certain period of time, which is usually very brief compared with the period during which the cycle of E. M. F. reversal is accomplished. In other words, in nearly all cases the current in the cir-

cuit has become steady in direction before the next reversal takes place. There is, however, an abrupt interchange of electric energy necessary in order to reverse the condition of electric and magnetic fluxes developed around the conductors in space. For example, if we consider a telephone circuit from New York to Philadelphia, and that the telephoner in New York is uttering a syllable in a certain tone or note, this vocal note is inducing, in the manner already described, a periodic E. M. F., alternating say 1,000 times per second. In each thousandth of a second, therefore, there will have been a distinct series of waves, which at the speed of light travel to-and-fro along the wires. Taking the circuit length as 100 miles, each pulse, if unabsorbed, would require about the $\frac{1}{1,860}$th part of a second to complete its

passage, so that not quite two pulses can travel over the circuit before the state of affairs is completely reversed in direction. This demands that a greater supply of energy shall be called into action at the electromotive source or induction coil, than would be necessary if the electric condition surrounding the wires did not require reversal, since the entire electric and magnetic fluxes, extending around the wires for the 100 miles, have to be swung the opposite way, or reversed at each alternation. The effect of this is that the apparent resistance of the line is increased. If the resistance of the line and receiving telephone were, say, 2,000 ohms to a steady current in which mere absorption takes place into the conductors, including the wire in both line and telephone coil, the apparent resistance at a frequency of 500~ per second, or 1,000 alternations

per second, might be 6,000 ohms, and, although the rate of dissipation for a given current strength in the wire would be, for all practical purposes, the same as before, yet the energy of the source is partly diverted into effecting the rapid reversals, instead of being entirely expended in producing the rush of electric flux; *i. e.*, electric current.

As the frequency of alternation increases, the greater will be the amount of energy which must be diverted for the purposes of flux reversal, and the smaller the amount that can be spared to produce the current strength, so that the apparent resistance or impedance of the circuit will increase as the frequency rises. Moreover, the amount of energy, which is needed to effect reversal of the flux, will depend upon how much flux there is to reverse;

i. e., upon the distribution and condition of the flux, which, in its turn, depends upon the geometrical distribution of the conducting wires. If the two wires be remote from each other, or if a ground-return circuit is employed, so that a considerable loop area is contained between them, the loop has to be filled by electric and magnetic flux at each current wave, and the amount of energy to be diverted, although not expended, for purposes of reversal, will be increased; whereas, if the two wires be close together, as for example, if they are insulated and laid up in a single cable, the loop between the wires is small and comparatively little activity is required to keep the fluxes reversed in this loop. In other words, the impedance of a ground-return circuit, or of a metallic circuit in which the wires are far apart, is greater than the impedance of a metallic

circuit in which the wires are brought close together. On the other hand, however, when wires are brought close together, the effective or virtual thickness of the ether layer between them is diminished, and the density of the electric flux is increased for any given impressed E. M. F. between them. In ordinary technical language their electrostatic capacity is increased. Consequently, the absorption, which the electric flux undergoes in its first pulse along the wire during the period of building up the current, is much greater, and the retardation of the current strength is increased. For these reasons there is a definite distance between telephone wires, which, for a given resistance, is most advantageous for the best telephonic communication.

If we consider the single wire telephone

line represented diagrammatically in Fig. 111, the condition in the conductor will be different if the wire be of copper or non-magnetic metal, as compared with iron or magnetic metal. If of copper, the magnetic flux in it will be the same as though the wire were of ordinary air with an electrically conducting hole of the same cross-section as the conductor, and the intensity of the magnetic flux in it will be comparatively feeble for any ordinary telephonic current strength. On the other hand, if the wire be of iron, the same magnetic force tending to produce a cylindrical distribution of magnetic flux around and in the substance of the wire, by the rush of electric flux over its surface, will set up a very powerful magnetic intensity in the iron of which the wire is composed.

The consequences of an iron-wire circuit

are two-fold. In the first place the development of the magnetic intensity will set up secondary attenuation in the electric flux travelling over the surface, so that the iron will virtually offer a higher resistance than its cross-section should allow; or, in other words, the conduction of current will be practically limited to a skin or superficial cylinder of the wire, the interior of the wire being of no value for conducting purposes, unless the frequency of current alternation is reduced, time being necessary to allow the interior layers to come into play. In the second place, more energy will be required to reverse a powerful magnetic flux in the iron, at each alternation, or current reversal, and this will increase the impedance of the wire. From these causes combined it follows that an iron wire offers a considerably greater impedance to telephonic

currents than a copper wire having the same *ohmic resistance; i. e.*, the same resistance to steady currents, or currents in which the steady state has been attained. On this account all long-distance telephone wires are now made of hard-drawn copper, instead of iron. For short distances, telephonic communication is practically just as good with iron wires as with copper wires, since the total impedance is small, but where telephones are installed which have to be brought into action on long-distance systems, it is undesirable to unduly increase the impedance, so that copper metallic circuits are rapidly coming into more extensive use.

When two telephonic circuits are near together, although completely insulated, they are capable of exerting marked disturbing electric influences on each

other. Fig. 112, represents diagrammatically two parallel telephone circuits which for simplicity are represented as having a ground return. When a periodically alternating E. M. F. is im-

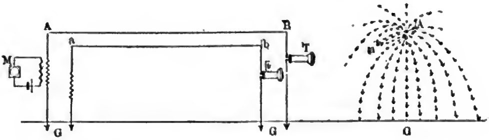

FIG. 112.—DIAGRAM REPRESENTING TWO PARALLEL CIRCUITS WITH GROUND RETURN.

pressed on the circuit *A B*, by the telephoner at *A*, two distinct influences will be produced upon the neighboring conductor *a b*. One of these influences is purely electric, and is called *electrostatic induction*. The other is purely magnetic, and is called *electromagnetic induction*. Suppose, for example, that the end *A*, is connected to a steady E. M. F., or battery,

while the end *B*, is insulated or disconnected from the telephone. The end *A*, being connected to the E. M. F. becomes charged, an electric flux will rush over its surface, becoming distributed from the conductor *A B*, as its base, to all neighboring conductors as the counterbase. The ground will receive a large portion of this flux, but the conductor *a b*, being itself connected with the ground, will also receive a share, which will depend upon the relative proximity of ground and conductors. This is represented diagrammatically on the right-hand side of the figure, where part of the flux, from *A*, is seen to terminate upon the neighboring wire *a*, while the rest of the flux terminates upon the surface of the ground. If *A* and *a*, are close together, a large percentage of the electric flux will terminate between them; while, if, on the contrary, *A*, and *a*,

are far apart, only a small quantity of the flux from *A*, will terminate on *a*. In other words, the electrostatic capacity between *A*, and *a*, will increase with their proximity. Motion of the flux along *A*, will necessitate a motion of that portion which terminates on *a*, along the surface of *a*, in the same direction, thereby inducing an electric current in *a*. An alternating electric current in *A B*, produced say by conversation, will, therefore, induce an alternating electric current in *a b*, of the same frequency, which may reproduce audible conversation in the telephone *t*, at *b*.

In addition to the above, when a current is flowing; *i. e.*, when electric flux is rushing along *A B*, magnetic flux will be established around *A B*, in closed cylinders of gradually diminishing intensity.

When the current is steady, the presence of some of this magnetic flux enveloping *a*, does not produce any electric disturbance in the wire *a b*, but when the current in *A B*, varies, the magnetic flux around *A B*, is undergoing corresponding variations in intensity, and this magnetic disturbance at the position of the wire *a b*, induces an E. M. F. in *a b*.

Regarded from a slightly different point of view, the wires *A B*, and *a b*, may be considered as two single loops of an induction coil in which *A B*, is the primary loop and *a b*, the secondary loop. Any changes of current strength in *A B*, will, therefore, induce a corresponding electromotive force in *a b*. If the circuit of *a b*, is closed, as indicated in Fig. 112, this induced electromotive force will establish a current in *a b*. Consequently, an alternat-

ing telephonic current in the circuit *A B*, will establish an alternating telephonic current of lesser intensity in the line *a b*, due to both electrostatic and electromagnetic induction from *A B*. Conversation overheard in this way on one wire, due to telephonic conversation on a neighboring wire, is commonly called "*cross talk*," and is one of the principal difficulties which telephonists have had to overcome in practice. So sensitive is the telephone, that wires which are situated parallel to each other, though many feet apart, will, if of considerable length, produce cross talk from one to another.

It is often difficult to ascertain whether cross talk is due to electrostatic induction, electromagnetic induction, or to an actual leakage of current from one line to another. Each of these influences is capable

of producing annoying interference, and although, strictly speaking, the effects are not exactly the same, yet practically the difference in effect is so small that they

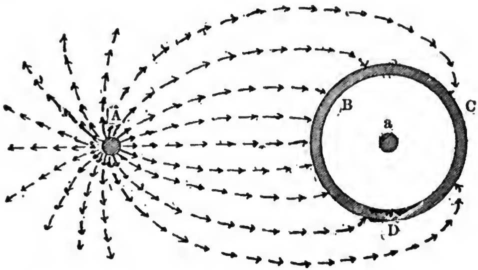

FIG. 113.—DIAGRAM OF ELECTROSTATIC SCREEN.

become difficult to distinguish. Electrostatic induction can be completely prevented between two wires by providing a middle partition or sheath between them. For example, in Fig. 113, two wires are represented at *A* and *a*. One of these is completely enclosed in a cylin-

drical metallic sheath $B\ C\ D$, as, for example, a thin lead pipe which is connected with the ground. Under these conditions any charge communicated to one of them, say A, will set up an electric flux which spreads out from the surface of A, and terminates upon the conducting sheath of a, but cannot penetrate into the interior. This is diagrammatically represented in the figure. Similarly, any charge communicated to a, cannot affect A. On the other hand, any magnetic disturbance occurring around A, by variation in the electric flux rush, or current, will induce electromotive force in a, which could only be entirely cut off by a perfectly conducting metallic sheath.

The manner in which the inductive influence which gives rise to cross talk is overcome will be understood from an

inspection of Fig. 114. Suppose A, is an active alternating-current conductor; *i. e.*, a conductor over the surface of which electric flux is rushing to-and-fro at periodic

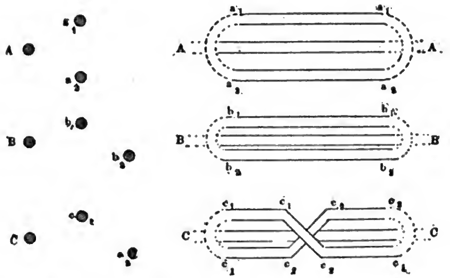

FIG. 114.—DIAGRAM OF INDUCTIVE CIRCUITS.

intervals and around which are expanding and contracting curves of magnetic flux intensity. Let a_1 and a_2, be two wires forming a metallic circuit, as indicated on the right-hand side. Then both the electrostatic and electromagnetic induction

which A_1 exerts upon a_1, will, by symmetry, be the same as it exerts upon a_2, but the influence of the E. M. F. in a_1, on the circuit $a_1\ a_1\ a_2\ a_2$, which will be just equal and opposite to the influence of the E. M. F. induced in the wire a_2, of the same circuit, so that these two oppositely induced electromotive forces will cancel or neutralize.

If as represented at B, in the same figure, the wire b_1, happens to be somewhat nearer to the active wire B, than its neighbor b_2, the electromotive force induced electrostatically, and electro-magnetically in $b_1\ b_1$, will be greater than that similarly induced in $b_2\ b_2$, so that a resulting electromotive force will act upon the closed metallic circuit $b_1\ b_1\ b_2\ b_2$, in the direction of the predominant component $b_1\ b_1$.

From this we learn that if the two wires forming a metallic circuit could always be situated at the same distance from a disturbing wire, there would be no resulting cross talk or induced E. M. F. in the metallic circuit, but if one wire happens on the average to be nearer the disturbing conductor than its mate, cross talk may be developed. At *C*, however, in the same figure, is indicated the solution of this difficulty. If the wires c_1 and c_2, are transposed at intervals, in the manner represented on the right-hand side at *c*, so that the nearer wire of one section becomes the further wire of the next section, the two components of E. M. F. will again become balanced, on the average, and no cross talk will result.

The reversal of the position of the wires shown in Fig. 114 is called a *transposition*.

The transpositions in the conductor forming a telephone circuit are in some cases made every few inches, while in other cases they may be made every few hundred feet according to the particular conditions. In order, therefore, to avoid the influence of cross talk between neighboring telephone wires, it is necessary not only that the circuits be well insulated from each other, but also that they are transposed relatively to each other at intervals.

The manner in which transposition is effected in the case of overhead wires is shown in Fig. 115. Here *a* and *b*, are two parallel wires arriving at a cross arm, while *c* and *d*, are two similar wires leaving the cross arm. Instead of *a*, being connected to *c*, or forming a continuation of *c*, and *b*, of *d*, as usual, all four wires are *dead-ended*, that is to say, bound to the

insulators on open circuit, but by the aid of two short cross wires, *a*, is put in connection with *d*, and *b* with *c*. When a number of telephone wires are supported

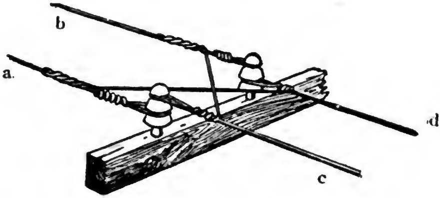

FIG. 115.—TRANSPOSITION OF OVERHEAD WIRES.

parallel to each other on poles, it is customary to transpose a few of the wires at certain intervals, say at each quarter mile. If this transposition is not effected, loud cross talk may be produced. A form of insulator intended for transposition and called a *transposition insulator* is shown in Fig. 116. It has two grooves,

one at *A*, and the other at *B*, each for the reception of one wire.

In the early practice of telephony, the conductors were almost invariably placed

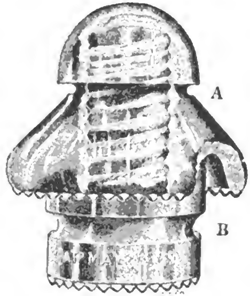

FIG. 116.—TRANSPOSITION INSULATOR.

overhead. The rapid growth of telephonic circuits necessitated the adoption either of underground cables in cities, or a number of wires were collected into a single cable and suspended overhead. Such cables are

called *aërial cables.* The cross-section of an underground telephone cable is shown in Fig. 117. This cable contains 128 con-

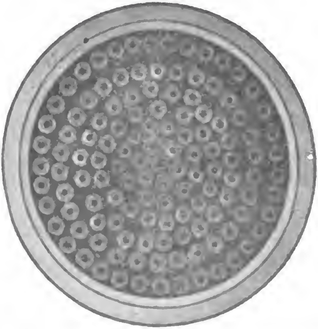

FIG. 117.—STANDARD TYPE OF UNDERGROUND TELEPHONE CABLE.

ductors, or 64 pairs, suitable for 64 metallic circuits. The conductors are commonly No. 19 B. & S., (36 mils in diameter) having a resistance of about 45 ohms per mile. These conductors are first

twisted in pairs having about four twists to the foot, and the pairs are then laid up together to form a cable. The number of conductors varies from 52 to 202. The insulating material is usually of dry paper. Occasionally, however, jute or other fibrous insulating material is employed. The sheath of the cable is made of lead so as to afford a water-tight as well as a mechanical cover. This sheath is applied in a hydraulic press, either warm or cold according to the particular process adopted. Where the cables are liable to be laid in creosoted wood conduits, it is found that the lead sheathings are apt to be corroded by impurities existing in the creosote. The admixture of a small percentage of tin in the lead not only hardens the material, but also renders it less liable to corrosion. It will be evident from the manner in which the individual wires forming each

conductor are transposed, that no appreciable cross talk can occur between the circuits. This, however, is entirely due to the fact that the conductors run as *twisted pairs.* If the individual conductors were employed in separate circuits, with ground returns, the cross talk would be so marked as in many cases to render telephony impossible.

Where underground cables are connected with overhead wires, special care is necessary to connect them in a water-tight box, called a *cable head.* The cable is brought up the side of the pole and enters the cable head, which is itself protected from rain by a box called a *cable box.* A simple platform is supplied beneath the cable box to enable the linemen to make connections conveniently. Fig. 118 shows a form of cable head. This consists of a

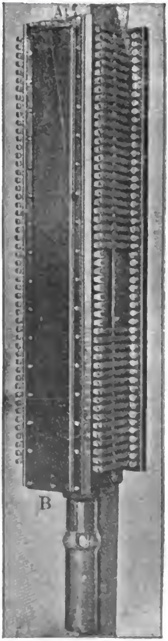

FIG. 118.—CABLE HEAD.

cast-iron box *A B*, from which issues a pipe, jointed to the leaden sheath of the cable at *C*. The wires, issuing from the cable, are spread out inside the box and are connected in proper order to a number of binding posts, which in their turn are connected through fuse wires to binding posts receiving the ends of the overhead lines. The cable head in the figure shows 52 pairs of binding posts on each side, and is capable of accommodating a cable with 52 metallic circuits, or 104 conductors.

Fig. 119, shows a cable box and platform mounted upon a pole beneath the cross arms. Here 80 overhead wires are brought into connection with a cable. Each overhead wire is dead-ended at its insulator, and insulated wires connect the dead ends to the proper binding posts of the cable head.

FIG. 119.—POLE AND CABLE BOX.

The disposal of the wires in an aerial cable is represented in Fig. 120, where the cable contains 100 conductors, each of No. 20 B. & S., making provision for 50 me-

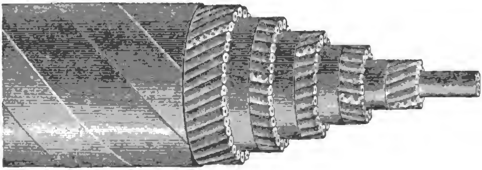

FIG. 120.—100 CONDUCTOR AËRIAL TELEPHONE CABLE.

tallic circuits. Fig. 121, shows a cable hook suitable for supporting an aërial cable. Since the weight of these cables is considerable, they are supported from a special steel wire immediately above them.

Aërial wire insulators are generally of glass, as used in telegraphy, of the form similar to that shown in Fig. 122. No. 12

B. & S., galvanized iron wire is commonly employed for short local lines, and No. 12 hard-drawn copper wire for lines that may be needed to connect with exchanges.

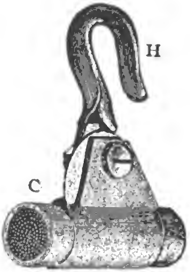

Fig. 121.—Cable Hook.

When passing through trees a form of insulator is commonly used, called a *tree insulator*, represented in Fig. 123. Here the wire and insulator are suspended from a wire made fast to the branch or trunk of the tree.

Telephone wires should not be carried on poles supporting electric light wires, but where it is necessary to do so, they should be so suspended, that if either

FIG. 122.—GLASS INSULATOR FOR AËRIAL LINES.

a telephone wire or an electric light wire breaks, it will not bring the two systems into contact. Moreover, the telephone wires should be frequently transposed in order to avoid inductive disturbances.

We have already alluded to the fact that, under certain circumstances, lightning protectors are necessary in a circuit to protect the instruments on the line from the

FIG. 123.—TREE INSULATOR.

effects of lightning discharges. When a lightning discharge occurs, an electrified mass of vapor or cloud discharges disruptively to the ground or to a neighboring cloud. All electric conductors in the vicinity of these discharges are subject to more or less violent *inductive disturbances;* that is to say, E. M. Fs. are induced

in neighboring conductors. If these conductors are situated in the immediate vicinity of the discharge, and occupy considerable area, these induced E. M. Fs. may be very powerful. On the contrary, when remote, and of small length or area, they may be inappreciably small.

It is well known that a telephone circuit, employing a ground return, will render audible disturbances due to lightning discharges, although many miles distant. These induced E. M. Fs., when powerful, may send brief but very dangerously powerful currents through telephonic circuits. These currents might give a powerful shock to the telephoner and might even destroy the apparatus. In order to avoid this, various devices called *lightning arresters*, or *lightning protectors*, have been devised.

A simple form of lightning arrester is shown in Fig. 124. Here the line wire passes to the telephone apparatus through a brass plate *A B*, which presents a serrated

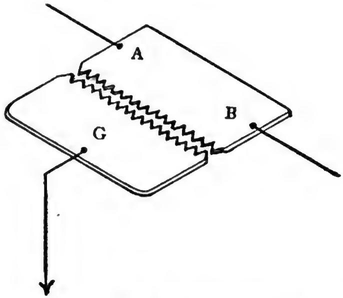

FIG. 124.—SIMPLE FORM OF LIGHTNING ARRESTER.

or jagged edge to a parallel plate *G*. The latter plate is connected with the ground in the neighborhood, either by a buried plate or more commonly through gas or water pipes. The two serrated jaws of the brass plates are separated by a narrow air space,

and are, therefore, insulated from each other. If, however, a high E. M. F. of say 1,000 volts or more, is connected between the plates, a disruptive discharge will occur between them. In other words, the thin layer of air between the opposed pointed surfaces will break down at an electric pressure which may be about 1,000 volts, and will permit a discharge to occur; or, in other words, will short-circuit the apparatus to ground.

If the resistance of the telephone apparatus to ground, should be, say 500 ohms, it would require a current strength of 2 amperes passing through it to produce a pressure of 1,000 volts, capable of disruptively discharging across an air-gap, but since lightning discharges are of a rapidly oscillating type, that is to say, have a very high frequency, the impedance which the

apparatus offers to the E. M. F. induced by lightning, is very much greater than the ohmic resistance. Consequently, a much smaller current strength passing through the apparatus will permit of a C. E. M. F. being established capable of disruptively discharging the line. This form of lightning arrester is in common use on apparatus employed in country districts, where aërial wires are employed.

Inductive disturbances due to lightning are not experienced on circuits in which the conductors are placed underground, so that for wires in cities where all the conductors are underground, such forms of arresters are not required. On the other hand, in cities, conductors are liable to be brought into accidental contact with high-pressure systems of electric lighting and power transmission, so that protection

from high pressures becomes necessary, although lightning may no longer be the source of such danger.

There are two distinct methods of ensuring protection from dangerously high E. M. Fs. The first is based upon the power which a high E. M. F. possesses for effecting a disruptive discharge across a narrow air-gap on the principle already described. The second consists in utilizing the ability which a powerful E. M. F. possesses of sending a current sufficiently strong to melt a piece of readily fusible conductor situated in its path, thus breaking the circuit. In standard long-distance telephonic apparatus, both these methods are employed.

A common form of protective device, called a *combination protector*, is repre-

sented in Figs. 125 and 126. On an insulating base *a a*, are mounted four terminals *i*, *i′*, and *o*, *o′*, respectively. *i* and *o*, are the terminals to which the in-

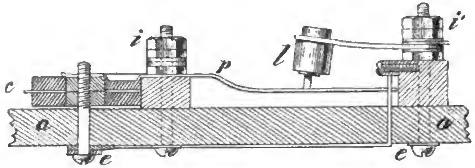

FIG. 125.—COMBINATION PROTECTOR.

coming and outgoing wires are attached. *i′* and *o′*, are the corresponding terminals of the telephone. Under normal conditions *i*, is connected to *i′*, and *o*, to *o′*. If, however, the pressure between either line and the ground should become excessive, or if the current strength passing through the telephone should become excessive, one or both lines will become automatically grounded. When both lines become

grounded the telephone apparatus is short-circuited. On the left hand side near the line terminals *i* and *o*, is a brass plate *b*, with a terminal *e*, permanently and directly connected to ground. Upon this

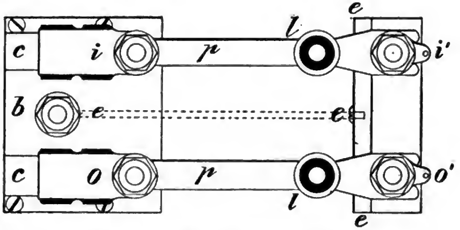

FIG. 126.—COMBINATION PROTECTOR.

brass plate are mounted two sheets or strips of carbon, which are, therefore, themselves connected to ground. Over these strips of carbon are laid thin sheets of mica, with a perforation or hole near the centre. Over these sheets of mica are two additional carbon plates which are con-

nected by spring contacts with the terminals i and o. Consequently, the line carbons are insulated from the ground carbons immediately beneath them by the perforated mica plate. If the pressure rises to about 300 volts, between either pair of plates, a spark discharge will occur through the perforation or air space between the carbon plates. A drop of fusible metal being let into the upper carbons at this point, a permanent grounding will take place through the perforation between the upper and lower carbon, thus establishing a permanent ground on that line. Under normal conditions insulation is maintained between the carbons, and the incoming current passes through the bent German silver strip p, to the metallic point of a small coil l, which is itself supported by another metallic strip, from the terminals i', or o'. The small coil is composed

of fine German silver wire having a resistance of about 28 ohms. A steady current of 0.4 ampere will generate in this coil sufficient heat in thirty seconds to melt a small capsule of fusible metal at the top of the coil. This capsule supports a metallic pin in the centre. Consequently, when the capsule melts, the pin is forced upwards under the pressure of the spring *p*. The extremity of *p*, is thus enabled to come in contact with a strip of brass connected directly to ground by the wire *e e*. If then, the pressure is not excessive, but the current strength in the telephone amounts to 400 milliamperes, the apparatus will be grounded and cut out of circuit before damage is done to the bell coil.

Fuses are introduced in cable heads, and where cables are brought into central

stations, more for the purpose of protecting the cable from injury than for ensuring protection to the subscriber's apparatus which may be in circuit.

CHAPTER XIII.

LONG-DISTANCE TELEPHONY.

Long-distance telephony differs from ordinary telephony only in details of apparatus and circuits. As the length of circuit increases, it becomes more and more difficult to obtain loud and distinct reproduction of speech in the receiving instrument. This is due to two causes:

(1) To the attenuation or reduction of the received current strength by reason of the high impedance of the circuit; and,

(2) To the failure of the receiving instrument to reproduce correctly the quality of the sounds, due to the fact that the intensities of the different overtones are not

correctly reproduced as regards their amplitude, the shriller and, therefore, higher frequency overtones suffering greater attenuation in transmission than the lower tones.

Failure in the transmission of speech due to attenuation, or great impedance, of the circuit, may occur on shorter lines by the insertion of a high artificial impedance. For example, an imperfect contact, a loose connection, a large choking coil, or any high resistance generally, will so far reduce the current strength in the circuit as to render transmitted speech inaudible. The remedy for this difficulty is the elimination of all undue resistance, the adoption of low resistance conductors, the employment of a more delicate or more carefully adjusted receiver, and of as powerful a transmitter as possible. In fact, it becomes essential

to increase the current strength according to Ohm's law by increasing the E. M. F. and diminishing the impedance.

The impedance of a line is the resultant of several causes. First, the ohmic resistance, depending upon the cross-section, length and character of the conductors employed. This cause would exist in a continuous-current circuit. All very long distance circuits must, therefore, have as little resistance as is commercially practicable. A diminution of resistance in conductors is only obtained by increasing the size and, therefore, the cost of the copper wires. The wire ordinarily adopted for long-distance circuits is No. 12, B. W. G., having a diameter of 0.109″ and a resistance of 4.6 ohms per mile.

The second factor in the production of

impedance is the *insulation resistance* of the lines; that is, the resistance which is measured either between each line wire and ground, or between the two lines forming a metallic circuit. Although a very high degree of insulation represents a very small loss of current by leakage along the line, yet such high insulation is not in general suited for the best results in long-distance transmission of speech. On the other hand a very low insulation, with correspondingly increased leakage of current, renders the received current so feeble that the limiting transmitting distance is rapidly reached. There is, therefore, for every circuit, a particular condition of insulation which is best adapted to long-distance transmission. The insulation should always be good and uniform, but should not be exceedingly high for the best results.

The third factor in the production of impedance is the *electrostatic capacity* of the line, or its power to act as a condenser. The greater the electrostatic capacity, the greater the amount of electric flux which can be established between the conductors, per mile or per foot. The presence of this electrostatic capacity acts deleteriously in the transmission of electric waves, instead of permitting the flux to travel quickly from one end of the circuit to the other. The flux, although moving with the velocity of light, is rapidly absorbed as it runs in order to fill the dielectric or charge the system. The nearer the two conductors are brought together the greater will be the electrostatic capacity, and the greater will be the impedance which the line will offer to the transmission of speech. The higher frequency waves will suffer more than the lower frequency waves. In

cables the two wires forming the circuit are brought very close together and hence the electrostatic capacity is considerably increased. For this reason long lengths of underground or subaqueous cable are very unfavorable to long-distance telephony. The two or three miles of cable which may be needed within city limits, may offer as much effective impedance as twenty times that length of overhead wire. Every effort is made to reduce the electrostatic capacity of subterranean cables, and the capacity per loop mile of cable conductors is only about ten times as much as the capacity per loop mile of overhead wires. Under present conditions, however, it would be practically impossible to transmit speech telephonically from New York to Chicago if the entire wire consisted of buried cables.

The fourth factor in the production of

impedance is the *electromagnetic capacity* or *inductive capacity* of the circuit, the same influence as produces the choking effect, in a magnet or a coil of wire. Here the magnetic flux, developed by the movement of the electric flux through the circuits, sets up an E. M. F. tending to oppose the development of an alternating current. This influence becomes more marked as the frequency increases. The electromagnetic capacity, or *inductance*, as it is termed, of the conductors forming a circuit increases with their distance from each other. It is much greater with iron than with copper conductors, and for this reason copper wires are always employed in long-distance telephony.

The effect of electromagnetic capacity, or of *self-induction*, always reduces the current strength in the circuit when it is

developed in apparatus. That is to say, a large inductance in the receiving apparatus is prejudicial to the development of a powerful telephonic current in it, and this objection increases with the frequency. On the other hand, all electromagnetic apparatus must possess inductance in order to be able to operate, since an instrument devoid of inductance would be necessarily inoperative. The best results are obtained when the inductance introduced is such that further addition reduces the loudness of the transmitted sound.

The effect of electromagnetic capacity in the line, that is to say, between the parallel conductors forming the circuit, is not necessarily prejudicial to the development of telephonic current strength in the receiver. If electrostatic capacity were absent from the line, then electromagnetic capacity or

inductance would be as detrimental to current strength, as it is when developed in the receiving apparatus, but being associated with electrostatic capacity along the line, the influence of the one is opposed to the influence of the other, and, when properly adjusted, they can be caused largely to neutralize each other.

The total impedance of a long telephone circuit is, therefore, much less by reason of its inductance than it would be if the inductance were absent, since every line necessarily possesses electrostatic capacity. In overhead lines, and especially in cable conductors, the electrostatic capacity is greater than is needed to balance the electromagnetic capacity, so that it is generally advisable to increase the inductance of the line when very long distance transmission is desired. This is best accom-

plished by spreading the wires further apart on the cross arms of the poles, so as to increase their electromagnetic capacity, while at the same time reducing their electrostatic capacity. In the case of cable conductors, the electrostatic capacity is so far in excess of that required to produce the lowest impedance, in conjunction with the electromagnetic capacity, that it might be advantageous to insert coils of wire at intervals in the circuit for the purpose of increasing the effective magnetic capacity. It is theoretically possible so to balance the conductor resistance, and conductor leakage, with the electrostatic and electromagnetic capacities, that the circuit will only offer a certain minimum impedance to a telephonic current, which will not distort or affect its frequencies differentially. But at present it is impossible to produce conductors

which will combine these constants in the proper proportions to effect this result.

The longer the circuits that are employed for telephony the greater the care that must be exercised in their construction, since the greater becomes the probability of accidental derangement. So securely have long-distance telephone circuits been erected in the United States, that on several occasions they have formed the only connecting lines between distant cities during severe storms when all telegraph lines have been blown down or interrupted.

The longest telephone circuit, in point of distance, is the New York and Chicago line, which is 950 miles in length, that is to say, it is composed of 1,900 miles of conductor. The conductor is No. 8 B. W. G.

hard-drawn copper wire, 0.165″ in diameter, having a resistance of 2.05 ohms per mile, and weighing 435 pounds per mile, so that the total weight of the wire is over 400 short tons. The line was opened on October 18, 1892. The use of cables in this circuit has been avoided as far as possible, and the wires are transposed at suitable intervals. The poles are of cedar or chestnut, 35 feet and upwards in height, and average 45 to the mile. Successful conversation has been carried on over this circuit, by extension, between Boston and Milwaukee. By successive connection of several lines, the longest distance, over which regular telephonic service extends, is between Memphis, Tenn., and Boston, Mass., a distance of 1,538 miles.

The maximum distance to which tele-

phonic speech can be successfully transmitted, is impossible to define. The question is more of a commercial than of an engineering nature. If the impedance of the line can be sufficiently reduced, telephonic communication is always possible, provided that inductive disturbance is avoided. The electrostatic and magnetic capacity increase in direct proportion to the length of the line, as also the resistance and leakage of the conductor. By sufficiently reducing the resistance of the conductor, that is to say, by sufficiently increasing its cross-section, the impedance can always be reduced. As, however, the copper wires are increased in diameter, their effective cross-section becomes slightly reduced, owing to the fact that the electric flux, travelling along the surface, finds its entrance into the interior of the wire opposed by magnetic influence.

When very large wires are used, therefore, it would be necessary to subdivide the conductor by *stranding* it; *i. e.*, by forming it of a number of smaller wires laid side by side having the same aggregate weight. This precaution has never yet been necessary for existing lines, the largest wire being 0.165″ in diameter.

It may be regarded as within the capability of existing apparatus and high-class circuits to transmit speech audibly, a distance of 2,000 miles over land. The problem of transmitting speech through submarine cables is a much more difficult one, 100 miles being the approximate limiting distance in such cases. This is owing entirely to the large electrostatic and small electromagnetic capacity of the circuit. It would be theoretically possible to telephone across the Atlantic by employing

subdivided conductors, of sufficiently low resistance to reduce the impedance of the circuit to the necessary limit, but practically, it may be either extremely difficult, or even absolutely impossible, to carry this into effect, while the great cost of the undertaking renders it under existing conditions commercially prohibitive.

The telephonic current strength which a given impressed E. M. F. at the sending end can produce in the receiver, diminishes more rapidly than the length of the line, that is to say, a uniform telephonic circuit, 1,000 miles long, will deliver to the distant receiver less than one half of the current strength which would be delivered from the same impressed E. M. F. if the circuit were only 500 miles long. On the other hand, the received current does not diminish so rapidly as the square

of the length, that is to say for the 1,000 mile circuit it would probably be less than one-half and more than one-fourth of the current received over the 500 mile circuit. It would perhaps be about one-third the exact value, depending not only on the impedance of the receiving and transmitting apparatus, but also upon the resistance, leakage, electrostatic and electromagnetic capacities of the lines. It has sometimes been supposed that the product of the total resistance and the total electrostatic capacity of the circuit was a measure of its actual impedance, and, therefore, varied inversely as the received current strength. Such a supposition, however, involves the result that the received current strength varies inversely as the square of the length of the circuit, and disregards the effect of the electromagnetic capacity of the line. Conse-

quently, this supposition, sometimes called the *KR law,* is unreliable for long distance circuits, although for short lines its results appear to be practically reliable. No theory of long-distance telephony can safely ignore the effects of electromagnetic capacity and of leakage.

Fig. 127, shows the switchboard of the long-distance telephone exchange in New York City. Here the operators are in communication by *trunk-line wires* with distant cities, on the long-distance system, and with local exchanges in New York City. Calls arrive both from the long-distance lines seeking connections in New York, and from the local exchanges asking for connections in distant cities. As soon as a subscriber, let us say No. 1,000, Franklin, asks for connection, say with No. 3,739, Philadelphia, the operator at the

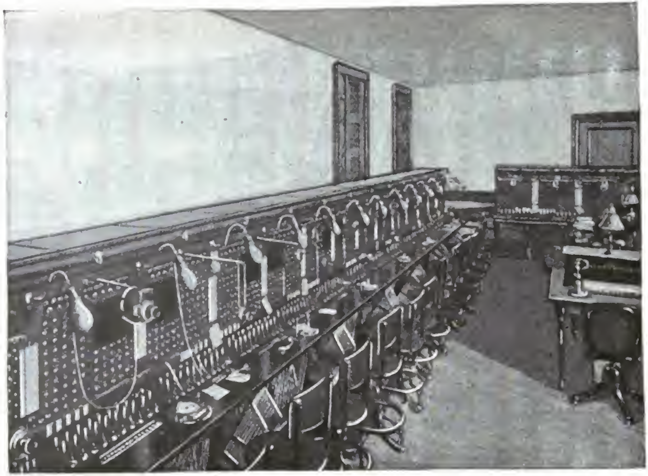

Fig. 127.—The Switchboard of the Long-Distance Telephone Exchange, New York.

Franklin exchange calls on a trunk line, the operator at the long-distance exchange. This operator on receiving the call, makes the inquiry on the trunk line to Philadelphia, where in turn the local operator calls up the subscriber needed. The following connections are then established; first, the Franklin Street operator connects subscriber No. 1,000 with the trunk line to the long-distance exchange; second, the long-distance exchange connects the trunk line from Franklin Street with the line to Philadelphia; and third, the operator at the Philadelphia exchange connects the long-distance line from New York with the line of 3,739.

Since the charge made for long-distance service is based upon the time during which the conversation lasts, the rates being in this case one dollar for five minutes con-

versation or less, it is necessary to keep a careful count of the time during which

FIG. 128.—THE CALCULAGRAPH.

the line is employed. A convenient method for accomplishing this is by means of a machine called the *calculagraph*.

This machine is represented in Fig. 128. It consists of a clock with its dial on the top of the instrument as shown. There is provided a front plate p p', and two handles H, H'. When the calculagraph is employed in connection with long-distance telephony, a slip of paper is inserted below the front plate p p', and the right hand handle H, is rocked first backwards from, and then forwards, or towards the plate.

The first impulse prints on the slip the time of day, as shown on the right hand side of Fig. 129, under the words "Time Connected." The second impulse prints the two left hand dials represented on the left hand side of the figure under the words "Elapsed Time."

As soon as the conversation is over and the subscribers ring off, the left hand

handle H', is pulled toward the plate with the slip again inserted. This prints the arrows on the left hand dials, marking off

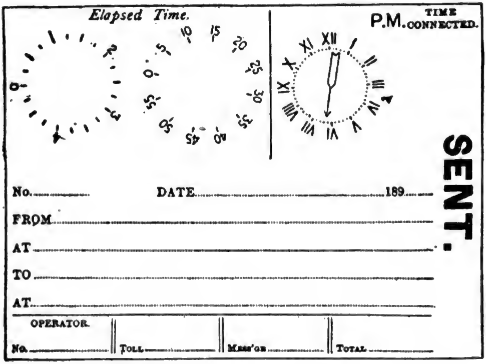

FIG. 129.—CALCULAGRAPH RECORD.

the time which has elapsed, as in Fig. 130, where it will be seen that the time elapsed was 7 1/2 minutes. It is not neccessary that the calculagraph should be reserved for a single slip, since any num-

ber of slips can be printed in succession, and the elapsed time between the prints is always faithfully recorded no matter what the order in which the slips are presented.

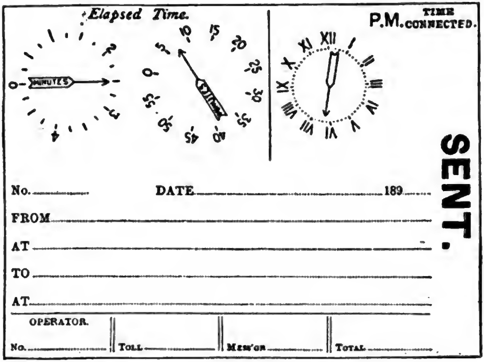

FIG. 130.—CALCULAGRAPH RECORD.

In Fig. 127, the calculagraphs are to be seen, set into the operating desk of the switchboard, so as to be readily reached by the operators.

Fig. 131, shows a *long-distance cabinet booth.* It is intended to afford an enclosed space where the telephoner's conversation will not be overheard, and where also external sounds are excluded. It is made as nearly sound proof as possible, by making the doors, roofs and sides double.

By reference to Fig. 68, it will be seen that when a telephone is employed in conversation, the secondary winding of the induction coil is included in the line circuit. Since this is only needed during speaking, or sending currents, and not during listening or receiving currents, it is evident that the presence of the secondary coil in the lines produces an unnecessary and deleterious impedance in the circuit at the receiving end. For long-distance service, where in order to hear clearly, it is important to reduce all impedance as

FIG. 131.—LONG-DISTANCE CABINET BOOTH.

far as possible, arrangements are usually made to cut the secondary coils out of circuit during listening. This is done by a button which is usually placed in the centre of the desk as shown in Fig. 130. To use this button requires some little attention or practice, since it is necessary to press it down during listening, and to release it while speaking. Its use is, therefore, left optional.

When connections are established in long-distance telephony, it is sometimes inadvisable to connect two lines together. For example, a long-distance circuit is always a metallic circuit, and when a subscriber with a long-distance telephone desires to be connected to a subscriber in a distant city, who has a ground return, the connection of these two circuits may destroy the anti-induction balance on the

metallic circuit of the long-distance system, and produce much disturbance and cross-talk. To avoid this difficulty, the two circuits are often connected inductively. This is, in reality, causing them to communicate by cross-talk, exaggerating the conditions under which cross-talk is produced. The apparatus consists of an induction coil in which the two windings have equal numbers of turns, one winding being connected to one circuit and the other winding to the other circuit. Any variation of current in one winding will then cause a variation of magnetic flux to pass through the other, and so establish a corresponding E. M. F. in the same. A form of such apparatus, called a *repeating coil*, is shown in Fig. 132. Here *A*, *B*, are strips of thinly laminated iron forming the core. *W W*, is the double-winding, and *T*, *T*, *t t*, are the terminals of the respective coils.

Some cities employ a system of connection between subscribers and the exchange, known as the Law system. The connec-

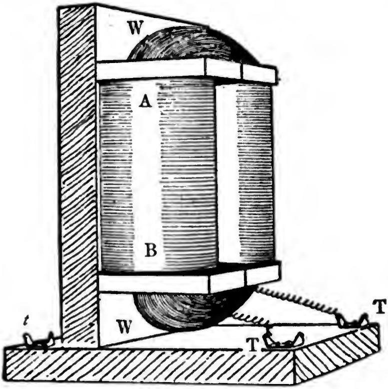

Fig. 132.—Standard Repeating Coil.

tions for such a system are diagrammatically indicated in Fig. 133. Here, the central exchange *S*, has the subscribers *a*, *b*, *c*, *d*, *e*, *f*, in a certain district connected

with the switchboard by metallic circuits in the usual way, but instead of permitting each subscriber to call up the operator

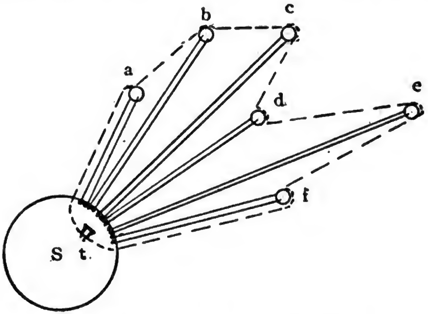

FIG. 133.—DIAGRAM OF LAW SYSTEM.

on his own wires, these are left open and a common call-wire circuit, indicated by the dotted lines, runs from the central exchange through all the subscribers' offices in that group. About seventy subscribers are usually connected together on

a single call wire, and the call-wire circuit is always completed through the head telephone of the operator at the exchange.

When one subscriber desires to call another, he introduces his telephone apparatus into the call-wire circuit, and is, therefore, in immediate communication with the listening operator. He gives his own number, say No. 55, and also the number he desires to communicate with, say No. 110. He, therefore, says to the operator, "No. 55 wants No. 110." The operator takes a pair of cords and inserts one plug in jack No. 55 and the other in jack No. 110, provided that 110 is not busy.

The Law system possesses the following advantages; namely, all the subscribers being in constant communication with the

central office, can obtain prompt attention. Moreover, there is the minimum amount of work to be done to connect one subscriber with another; consequently, the system is capable, under favorable conditions, of providing very swift service. The system possesses, however, the following disadvantages; first, it requires the running of additional wires for the calling circuits; second, any interruption of the call-wire circuit is liable to disable the apparatus of a number of subscribers; third, when many subscribers are on a busy call wire, delay is occasioned by waiting for the turn of each, and an impatient subscriber may greatly impede business; fourth, where many calls have to be trunked out, the system is at a great disadvantage, for the operator receiving a trunk call has to take her attention off the call wire, and communicate with the trunk

line operator, thereby introducing disturbance and delay. Briefly, then, this system possesses marked advantages for cases where the subscribers are all connected to a single switchboard, but where a city is split up into districts, so that trunking out is necessitated, the system fails to be advantageous.

Fig. 134, shows a form of long-distance telephone arranged on the Law system. *M*, is the solid-back carbon microphone transmitter; *C*, is the induction coil; *N*, is a button set at the side of the apparatus, for use in listening on long-distance circuits. Pressure upon this button short-circuits the secondary of the induction coil. *B*, is the call bell. *T*, is the telephone, suspended on an automatic switch, which on rising closes the local circuit of the transmitter. *S*, is a switch for introducing the

FIG. 134.—LONG-DISTANCE TELEPHONE APPARATUS.

apparatus upon the call wire, and *X*, the box containing two voltaic cells for the local microphone circuit. The front cover of the instrument is, in this case, removed, in order to show the interior apparatus.

CHAPTER XIV.

RADIOPHONY AND MISCELLANEOUS APPLICATIONS OF ELECTRICITY.

We have hitherto described the various methods in practical use for transmitting articulate speech by the aid of electrically conducting wires. It has been found possible, however, to transmit speech to limited distances without any wires, along rays of sunlight. The method by which this is accomplished is illustrated in Fig. 135. Here rays of sunlight impinge upon a mirror *M*, and are reflected through a suitable lens l_1, and fall upon a polished metal diaphragm *D*, clamped before the mouthpiece *M*. The beam after reflec-

tion from the diaphragm passes through another lens l_2, and reaches the distant parabolic reflector *R*. Here the rays converge to the focus of the reflector and are received upon a selenium cell *S*, which is

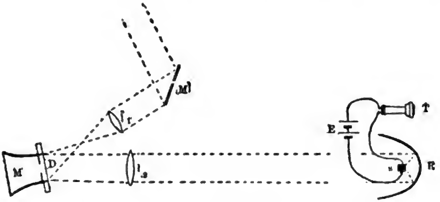

FIG. 135.—DIAGRAM REPRESENTING RADIOPHONIC TRANSMISSION.

in circuit with a voltaic battery *E* and telephone *T*. A selenium cell is formed of a grid of conducting wires connected by a fused mass of selenium. This substance has the property of varying its electric resistance, within certain limits, under the influence of light. If a person speaks

into the mouthpiece *M*, he causes the diaphragm *D*, to vibrate, and thereby throws the reflected beam into periodic variations of intensity, with a frequency corresponding to the frequency of the vocal waves. The effect of the variations in the intensity of the transmitted beam in the receiver *R*, is to vary periodically the resistance of the selenium cell with a frequency also corresponding to that of the vocal waves impressed upon the diaphragm *D*, and the telephone in circuit with the selenium cell, will thereby be caused to reproduce sounds of the same frequency.

The appearance presented by the transmitting apparatus is shown in Fig. 136. Here the mirror *M*, receives the sunlight and reflects the beam upon the diaphragm *D*, which is set in vibration by vocal

sounds uttered before the mouthpiece. The reflected beam from the diaphragm is transmitted direct to the distant receiver in the direction of the arrow at *P*.

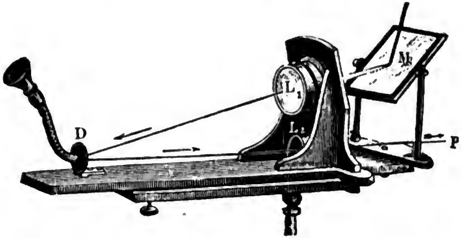

FIG. 136.—THE TRANSMITTER OF A PHOTOPHONE.

The distance to which the *radiophonic transmission* can be extended, depends first upon obtaining an uninterrupted line of view between the receiver and transmitter, and, also upon the sensitiveness of the apparatus. This apparatus must yet be regarded as of scientific rather than of practical value. The actual distance to

which radiophonic communciation has been carried is only a few hundred feet. It is, however, interesting to note that telephonic communication can be carried on along rays of sunlight.

A selenium cell is represented in Fig. 137. Here a number of brass discs are mounted in a cylindrical column with intervening insulating sheets of mica. As represented in the upper part of the figure, the alternate discs of brass are connected together to form one electrode and the remainder to form the other. The whole column, being clamped together, is heated above the temperature of melting selenium and a stick of selenium is then rubbed over the serrated surface. In this way a cylindrical surface of selenium is provided with a large electrode surface. The resistance of an apparatus made in this way

is about 1,200 ohms in the dark and 600 ohms in daylight. A great variety of dif-

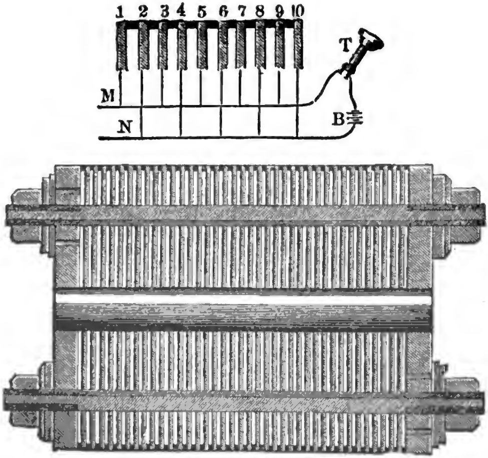

Fig. 137.—Selenium Cell,

ferent types of selenium cells have been devised, all embodying the same features in different constructive arrangements.

Instead of selenium, carbon in the form of soot, has been employed as the receiving surface for the vibrating beam in connection with the telephone. A *carbon cell* or *soot cell* is represented in Fig. 138. Here

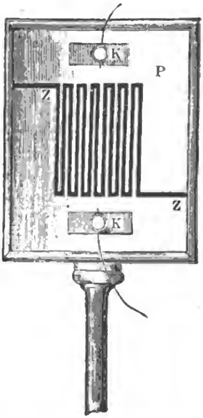

FIG. 138.—THE CARBON OR SOOT CELL.

a plate of silvered glass has its silver coating divided by a broad zigzag or furrow on

which the glass is exposed. The terminals *k* and *k′*, being connected each to the silvering at one end of the strip, are, therefore, insulated from each other. The furrow is then filled with soot which forms a short bridge of carbon between the terminals, and this surface is then exposed to the periodically vibrating beam of light. The periodic variation of the heat radiation falling upon the soot causes corresponding periodic variations in the resistance of the carbon and so causes a periodical vibration in the diaphragm of a telephone placed in circuit with the apparatus.

Just as the mechanical or string telephone is capable, as we have already seen, of carrying articulate speech over short distances without the intervention of electric currents, so it is possible to carry on radiophonic communication of speech,

as this method of transmitting speech along beams of light is called, without the aid of electric currents, and without even the aid of a receiving instrument. This is done by allowing the vibrating beam from the transmitter of Fig. 136, to fall upon a suitable sheet of material, such, for example, as a plate of hard rubber. The periodic expansion and contraction of the surface of the rubber, caused by the periodic variations of the heat received from the beam, causes the hard rubber disc to emit the sound waves impressed on the diaphragm of the transmitter. This property of substances thus to reproduce audible sounds under the influence of periodic variation in the radiation falling upon them is called *sonorescence.*

Attempts have been made from time to

time to telephone without wires. That this can be done, within certain limits, is shown by the existence of cross talk between neighboring insulated wires, since here telephonic communication is carried on through the space intervening between the parallel wires. Radiophony affords another example of telephonic transmission of speech without intervening wires, over a limited distance, through the aid of sunshine. But limiting the matter of telephony without wires, to actual cases where electricity is the communicating agent, it may be mentioned that telephonic communication has been extended to distances of a few hundred feet. If *A B* and *C D*, Fig. 139, two circuits, each employing a ground return and situated not too far apart, be operated, one with a transmitter at *M*, and the other with a receiver, say at *T*, the telephonic currents passing through

the circuit *A B*, will produce feeble currents in the circuit *C D*, and become audible in the telephone *T*. This influence may be exerted in a variety of ways.

First, by electrostatic induction, that is to

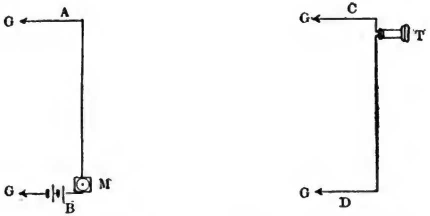

FIG. 139.—DIAGRAM REPRESENTING TELEPHONIC TRANSMISSION WITHOUT WIRES.

say, electric flux abutting upon the surface of the wire *A B*, will almost all terminate upon the ground in the vicinity of *A B*, but will extend in all directions with weakening intensity, and a small quantity of this electric flux will terminate upon the wire *C D*.

It is this portion whose periodic variation is capable of setting up a current that may serve to transmit speech in this manner.

Second, by electromagnetic induction. The rush of electric flux over the surface of the wire *A B*, must necessarily be accompanied, as we have seen, by the development of magnetic flux surrounding or linked with the wire. This magnetic flux will be most powerful in the immediate neighborhood of the wire *A B*, but will extend, with diminishing intensity, in all directions, and some small quantity of this flux will become linked with the wire *C D*; that is to say, it will thread the loop which is formed by the wire *C D*, and its ground-return circuit. The periodic variations of this magnetic flux, following periodic variations of the current strength in *A B*, will determine feeble

E. M. Fs. of corresponding frequency in *C D*, which may serve to reproduce the sound waves of the transmitter *M*.

Third, by conduction. The current in the circuit of *A B*, returned by the ground, does not find its way through a single path through the ground, but extends in all directions, permeating the mass of the earth. The current density will tend to be greatest in the straight line connecting the ground plates, but will diminish in intensity to all distances in every direction. In other words, the return circuit will spread out like lines of magnetic flux from the poles of a bar magnet. Some of this returning current will pass through the ground in which the ground plates of *C*, *D*, are buried, and will establish a feeble periodic difference of electric potential between the plates *C* and *D*,

which in turn will determine feeble periodic electric currents in the circuit *C D*, which may serve to reproduce the sound uttered in the transmitter *M*.

In such cases of telephonic transmission without connecting wires, all three causes; namely, electrostatic induction, electromagnetic induction, and conduction, are at work. The predominance of any one cause, in producing the effect, depends upon the local conditions of each case. In the case of cross talk, as it exists in practice between telephone circuits, it is induction that generally is responsible for the result. In many cases of experiments conducted as in Fig. 139, conduction is the principal cause. The co-existence of all three causes must, however, always be borne in mind.

Owing to the fact that the distance to

which electric telephony without wires has yet been carried is very small, little practical attention has yet been devoted to the subject. The reason for the limitation which has marked the distance of transmission in this case, is to be found in the fact that the periodic variation of current, which may be produced in the transmitting circuit *A B*, with existing telephone apparatus is comparatively small. When powerful electric currents transmitted by an alternating-current dynamo are sent through the circuit *A B*, instead of feeble telephonic currents controlled by a microphone transmitter, the distance to which audible sounds can be transmitted by this method has been increased from hundreds of feet to several miles. It is said, that between long parallel telegraph wires, Morse signals transmitted on a circuit such as *A B*, by the use of pow-

erful currents, have been observed by a telephone in a circuit $C\ D$, even when the distance between the two circuits was over 60 miles. In such cases the limiting distance simply depends upon the strength of the transmitting circuit current, and the sensitiveness of the receiving telephone, as well as upon the length and disposition of the two circuits.

In the ordinary telephone, as used to-day, the transmitted periodic electric current which carries in its variations the potentiality of reproducing the transmitted speech, does so by its electromagnetic properties. But it is possible to employ for the same purpose, effects of the current other than its electromagnetic effects. Such for example as its thermal, chemical or electrostatic effects.

A telephone which depends for its operation upon the thermal effects of the electric current is represented in Fig. 140.

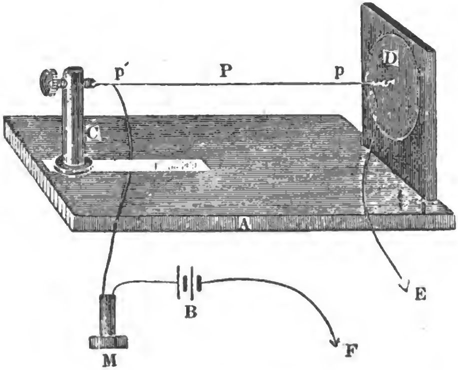

FIG. 140.—THERMO TELEPHONE.

Here the line is connected to the battery *B*, and then passes through the receiving telephone *M*, to the binding post *C*. From this binding post it passes through the fine stretched metallic wire *P′*, to the

centre of the diaphragm *D*, and thence by a ground wire to ground at *E*, or to a return wire, in the case of a metallic circuit. The periodic variation in the strength of the telephonic current causes periodic heatings and coolings of the resistance wire *P'*. This alternating heating and cooling causes a mechanical elongation and contraction of the wire, thus setting the diaphragm *D*, into vibration.

A form of telephone in which a chemical effect of the periodic current is relied upon is indicated in Fig. 141. Here the receiving diaphragm *D*, carries a metallic strip *a*, which rests upon a roller *A*, whose face is composed of moistened chalk. The axis of the roller is connected to one terminal and the diaphragm to the other terminal of the instrument. Means are provided for steadily rotating the roller under the spring, and thereby moving the diaphragm

with a force which depends upon the friction which exists between the strip and the surface of the roller. When an electric

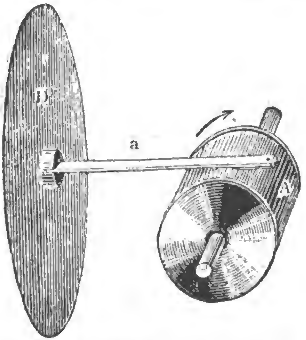

FIG. 141.—CHEMICAL TELEPHONE.

current passes through the strip and chalked surface, an *electrolysis* or chemical decomposition is effected of the moisture in the chalk. This causes oxygen to be liberated in small quantities at the positive pole, or the pole at which the cur-

rent enters the chalk, and hydrogen to be liberated at the negative pole, or the pole at which the current leaves the chalk. The development of hydrogen, even in very minute quantities under the spring *A*, and, therefore, on the surface of the chalk, very greatly diminishes the friction between the spring and surface, so that the diaphragm slips back or away from the roller. Periodically varying telephone currents therefore, tend to produce periodic slippings of the strip *a*, and determine the vibration of the diaphragm *D*. This telephone gives very powerful sounds and will fill a large hall with musical notes, although its articulation is imperfect. It also possesses the disadvantage of requiring to have the roller revolved during conversation. The connections of this instrument are shown in Fig. 142. Here *S*, is the microphone transmitter in circuit with the primary

winding of an induction coil *I*. The secondary winding is in circuit with the line wire and receiver *G*.

A form of receiving telephone in which

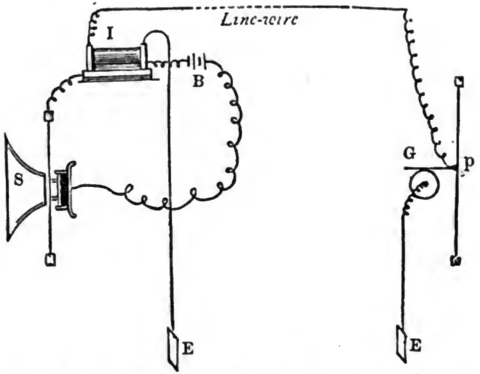

FIG. 142.—CONNECTION OF CHEMICAL TELEPHONE.

the electrostatic properties of the telephonic currents are employed is represented in Fig. 143. This receiver contains two

diaphragms, placed in close proximity to each other, one of which is the true vibrating diaphragm, and the other a fixed dia-

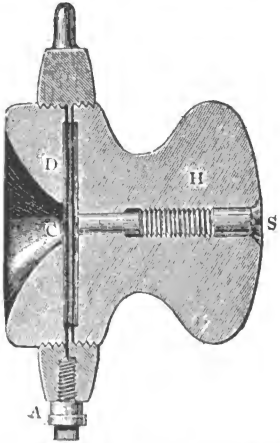

FIG. 143.—ELECTROSTATIC RECEIVER.

phragm connected to the ground. The front of the free diaphragm being connected to the line, any variation in electro-

static charge will cause the two diaphragms to vary in their electrostatic attractions for each other. Consequently, any periodic variation of E. M. F., acting on the line, sets up a corresponding varying electrostatic attraction between the fixed and free diaphragms, thus setting the free diaphragm into vibration and enabling articulate speech to be transmitted. With the use of this instrument, the line circuit is open and terminates at the receiver.

In addition to the preceding, many telephonic transmitters and receivers have been devised, operating on various principles. The receivers operate by electrostatic, electromagnetic, thermic, thermochemical, electrolytic, electro-capillary, actinic and other methods. It is the electromagnetic apparatus, however, which has come into almost universal use

owing to its marked superiority over all others.

As in telegraphy, it has been found possible to transmit several telephonic messages simultaneously over the same wire, either in the same direction, or in opposite directions. The first is called *multiple telephony*; the second is called *multiplex telephony*. Two messages in the same direction are called *diplex telephony*, three messages *triplex*, etc. Two messages in opposite directions are called *duplex telephony* and two messages simultaneously in each direction, or *duplexed diplex*, is called *quadruplex telephony* and so on. None of these methods have yet come into commercial use.

CHAPTER XV.

COMMON-BATTERY SYSTEMS.

One of the most important improvements which have been effected recently in central station telephony, has been the abolition of the local battery at each subscriber's station, and its replacement by a common battery, or a battery universal to all subscribers. The local battery has always been a source of uncertainty in maintaining reliable telephonic service, since the failure of the subscriber's battery in the ordinary system, such as is represented in Fig. 81, p. 197, results in the failure of that subscriber to make his voice heard by the party with whom he is placed in connection.

The central-battery or common-battery system is designed to supply the requisite current for the microphone transmitter over the subscriber's circuit in such a manner as shall dispense with the necessity of employing a separate battery at each subscriber's station. This change has been effected in nearly all the Bell central-station systems, notwithstanding the large expense necessitated thereby. Practically all large central-station systems are now equipped with some form of common-battery system.

A variety of common-battery systems have been worked out. It will suffice, however, to describe the Hayes common-battery method, which is employed in the Bell telephone system.

The connections at each subscriber's

station are indicated in Fig. 144, where *L*, *L*, are the two wires forming the metallic-circuit connections to the central station or

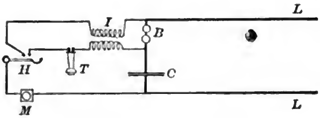

FIG. 144.—SUBSCRIBER'S CONNECTIONS, WITH TELEPHONE DISCONNECTED, COMMON-BATTERY SYSTEM.

switchboard. *B* is a bell, the coils of which are wound with fine wire, so as to offer a resistance of about 1,000 ohms, and an impedance of a much larger amount to rapidly varying alternating currents, the impedance being approximately proportional to the frequency. The bell is permanently connected between the subscriber's lines through the condenser *C*. This condenser is practically an absolute barrier to continuous currents, but offers a

fairly low impedance to alternating currents.

When the subscriber's telephone is left hanging upon switch-hook *H*, the two contacts at this switch are opened, and the two lines *L*, *L*, are only connected by the alternating-current path *B C*, indicated in heavy lines. The bell circuit is, therefore, open to alternating currents of low frequency such as are generated by the small low-frequency calling generator at the central station. To continuous currents, however, the two lines *L*, *L*, are normally insulated from each other at the subscriber's station. Under these circumstances the subscriber's bell will ring when the ringing generator with its low-frequency E. M. F. is connected to the subscriber's circuit.

When, however, the subscriber desires

to communicate with the central station, and lifts his telephone from the hook, the two contacts are closed at the hook-switch, as in Fig. 145. The lines *L*, *L*, are now directly connected through that

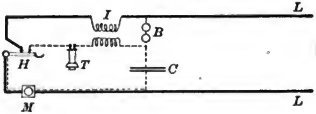

FIG 145.—SUBSCRIBER'S CONNECTIONS, WITH TELEPHONE LIFTED FROM SWITCH-HOOK FOR TALKING.

switch, one winding of the induction coil *I*, and the carbon transmitter *M*. At the same time a local circuit is also closed through the receiving telephone *T*, the other winding of the induction coil *I*, the condenser *C*, and the carbon transmitter. This local circuit is indicated in Fig. 145 in dotted lines. Placing the telephone in the local circuit keeps the full strength of

direct current supplied by the central station from passing through the telephone coils. It is evident from the figure that only a small fraction of the continuous current from the common battery at the central station can pass through the telephone, owing to the high resistance of the bell *B*, interposed in the telephone circuit. On the other hand, the full strength of the current received from the central station by the lines *L*, *L*, passes through the transmitter *M*. Although there are other advantages arising from the use of the induction coil, in addition to that of protecting the telephone from full continuous-current strength, as above mentioned, yet, for the purposes of simplicity, we may regard the subscriber's connections, when the telephone is lifted from the hook, as virtually reduced to those indicated in Fig. 146, where it will be observed that the sub-

scriber has his telephone and transmitter directly in circuit with the lines *L*, *L*, a permanent bridge or shunt path existing through the bell and condenser, which shunt path has so large an impedance to alternating currents of the frequencies of

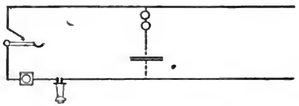

FIG. 146.—SIMPLIFIED SUBSCRIBER'S CONNECTIONS.

speech, that the loss of these currents by leakage through the shunt may be entirely neglected. Such a connection as is represented in Fig. 146 would be objectionable, if only for the reason that the full continuous-current strength in the circuit flows through the telephone, tending thereby to buckle the diaphragm and render it less sensitive, but with this reservation in mind

the simplified diagram of Fig. 146 may be retained in place of the more complex diagram of Fig. 145.

Fig. 147 represents diagrammatically the elements of the connections between the subscribers and the switchboard at the central station. The subscriber *B* is supposed to have his telephone hung up and his circuit interrupted. The line battery *L*, usually composed of a storage battery of 12 cells, or 24 volts, is permanently connected with these as well as with other subscribers' circuits. The connection with this line battery is established through the double contacts of a line cut-off relay *R*. As long as this relay remains unexcited, the subscriber's line is connected to the line-battery *L*, and is charged by the same. In the circuit of the line is the line relay *y*, the local circuit of which contains a small

incandescent lamp, or visual signal *l*, placed on the face of the switchboard. As long as subscriber *B* keeps his telephone hung up,

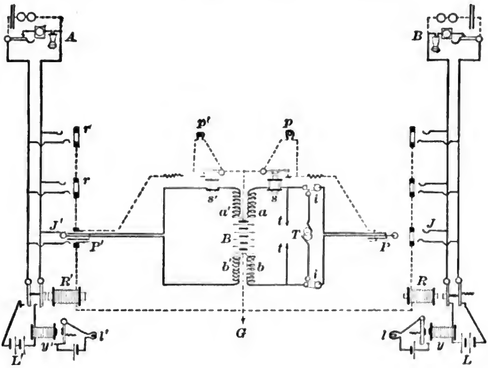

FIG. 147.—DIAGRAM OF CENTRAL-STATION SWITCHBOARD CONNECTIONS, COMMON-BATTERY SYSTEM.

the line battery *L* can send no current through the subscriber's circuit, and his line-relay *y*, remains unexcited. As soon as *B*, closes his circuit through the switch-

hook, by lifting his telephone, the line relay *y*, becomes excited, attracts its armature, closes the local circuit, and lights the lamp *l*, thereby calling the operator's attention. At any operator's position, all of the local circuits of the line relays terminating at that position pass through the coils of an extra relay, called the pilot relay, which is thereby enabled to light a pilot lamp when any one of the line relays is brought into action. This pilot relay and lamp is not shown in Fig. 147. Its purpose is to exercise a supervision over the duties of each operator by indicating at a single lamp when any line signal under her jurisdiction remains in action, or unattended to.

On the left-hand side of the diagram subscriber *A* is supposed to have called the central station by lifting his telephone,

thereby closing his circuit to the line battery L' and energizing his line relay y' and lamp l'. A's operator, in response to this signal, has inserted the answering plug P' of one of her pairs of cords into the answering jack J' of subscriber A. Three contacts are thereby established. The tip and ring of the plug are connected respectively to the two lines of A's circuit, thereby closing the circuit of the common battery B through the windings a' b' of the operator's induction coils, and the supervisory relay s'. At the same time the sleeve of the plug establishes a local circuit, indicated in dotted lines, through the common battery B and the line cut-off relay R' of A's circuit, thereby cutting off the lines of subscriber A from the line battery L', and extinguishing his line lamp l'. The current through this local circuit would pass through the supervisory lamp

p', and light it, if the supervisory relay s', excited by the main-line current, did not keep this lamp short-circuited.

A's operator is able to communicate with *A* by connecting her head telephone through a listening switch with the points t, t. On learning the number of the subscriber called for, who in the case represented is *B*, she is ready to insert the calling plug *P* of this pair of cords into the particular line jack of *B* which appears at her section of the multiple switchboard. Thus, if she should insert the plug *P* into the jack *J*, the tip and ring of this plug will be connected respectively with each of the two lines of *B*'s circuit, while the sleeve of the plug will close a local circuit through cut-off relay *R*, and will thereby break the connection between *B*'s line and his line-relay y, and line battery *L*. By

pressing the ringing key of this pair of cords, the connections would be changed in the manner indicated by the simultaneous turning of the two switches, *i*, *i*, thereby connecting a steadily running, low-frequency alternator *T* with *B*'s circuit. Meanwhile the lamp *p* is lighted by the current through the local circuit, indicated in dotted lines, and remains lighted until *B* lifts his telephone and closes his main line to the battery *B*, thereby bringing into action the supervisory relay *s* and short-circuiting lamp *p*. As soon as this lamp goes out the operator knows that *B* has lifted his telephone and is in communication with *A*. Under these conditions all of the four lamps l, l', p, p' are extinguished, and the connections between *A* and *B* are virtually those indicated in Fig. 148. Each subscriber may be regarded as having a local circuit through the

switchboard, including his telephone, transmitter, and a line battery. Inductive connection through the two induction coils or double induction-coil, establishes

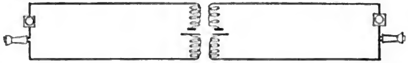

FIG. 148 —SIMPLIFIED CONNECTIONS BETWEEN TWO SUBSCRIBERS IN COMMUNICATION.

telephonic communication with the associated subscriber's circuit.

Each subscriber has, therefore, apportioned to him at the central station a line relay *y*, with its local-circuit line lamp in front of an operator, a cut-off relay *R*, an answering jack close to the line lamp, and a plurality of multiple jacks on the multiple sections of the board. Each pair of cords has a pair of induction coils *a*, *a'*, *b*, *b'*, actually associated into a single structure

and connected at the centre with the common battery *B*, which usually supplies the entire exchange. The line batteries *L*, *L′* are also usually connected into a single battery. These aggregate batteries have to supply an appreciable total strength of current during working hours, although the flow is practically stopped when all connections at the switchboard have been removed.

As soon as one of the subscribers, say *B*, has terminated the conversation by hanging up his telephone, his circuit is broken at the switch-hook. Consequently, supervisory relay *s* ceases to be excited, and opens its contact, thereby enabling the current in the local circuit or the dotted lines to light up the supervisory lamp *p*. This is a signal to the operator who made the connection that the conversation is

ended, and she proceeds to pull out both plugs, thereby extinguishing either or both of supervisory lamps p, p' and restoring the line batteries to connection with the subscribers' lines at the double contacts of the cut-off relays R, R'.

The local circuits in dotted lines also establish a busy test, by connecting all of the front contacts or rings of the jacks with a small potential difference produced by the local current flowing through the cut-off relay. Thus, with the plug P' in the answering jack J', all of the rings r, r, are charged with this potential difference relatively to the ground G, and any operator desiring to obtain connection with A and exploring any of these rings r with the tip of a calling plug, and with her listening key down, would receive a click in her telephone, on princi-

ples similar to those described in connection with Fig. 95 on p. 240.

The line lamps l, l', are all placed in one row in front of the respective operators of a multiple board, and the supervisory lamps p, p' in another row, so that each operator has only to insert plugs in answer to telephone calls indicated by line lamps l, l' and to withdraw plugs in response to supervisory lamps p, p'.

CHAPTER XVI.

VISUAL SIGNALS.

DURING the last few years small incandescent lamps have largely replaced electromagnetic indicators on central-station switchboards. The advantages of the incandescent lamp as an annunciator are that it very readily catches the eye of the operator, and, in fact, can be noticed from a considerable distance. Moreover, the space occupied on the surface of a switchboard by a lamp annunciator, or visual signal, is considerably less than the space taken by the ordinary drop signal, since the effective diameter of each lamp is only about 3/8″. The lamp is noiseless in

action, has no working contacts upon which dust can settle, is readily replaced when inoperative, and is cheaper than an electromagnetic annunciator. On the other hand, a lamp requires a relay to operate it, and also takes about 2.5 watts. The relays are, however, stowed away in dust-proof cases behind, or away from, the switchboard, where the space is less expensive than at the switchboard surface, and the power is only supplied for a few seconds at a time to any one lamp.

Telephone lamps are commonly made for 10 and 20 volts, the former being standardized at one quarter candle, and the latter at half candle. The tendency has gradually been shown to raise these pressures, which were originally about 4 volts, and which now sometimes reach 25 volts. The normal efficiency of these

lamps at rated voltages is about 0.18 candle per watt. Not only are such very small incandescent lamps somewhat inefficient by reason of their short filaments,

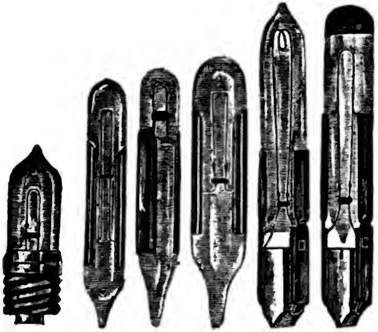

FIG. 149.—SWITCHBOARD LAMPS.

and the relatively large loss of heat by conduction from the ends of the filament, but they are designedly inefficient, in order to reduce the temperature of incandescence, and thereby prolong the lifetime, since the

annoyance, which might be caused by frequent failures of these lamps, would outweigh the value of the relatively small amount of power saved in them. Figs.

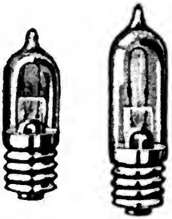

FIG. 150.—SWITCHBOARD LAMPS.

149 and 150, show different sizes and types of visual signal lamps.

The lamps are inserted end on, in recesses in the switchboard provided for them, and a small circular opal cover or cap seals the lamp from view while diffusing the light yielded over a circular area.

These opal glass covers are often tinted with different colors, or marked with distinctive signs in various ways to indicate visually the class of line, or to differentiate pilot lamps, supervisory lamps, and line lamps. A set of ten visual signals in a

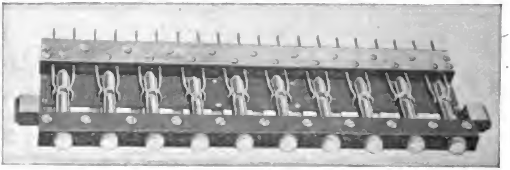

FIG. 151.—STRIP OF VISUAL SIGNALS FOR INSERTION IN SWITCHBOARD.

strip for insertion in a switchboard is shown in Fig. 151.

The line lamps are generally inserted in the switchboard immediately beneath the answering jacks of the respective lines, so

that the operator has only to point the answering plug at the line lamp lit up, in order to find the right answering jack. The supervisory lamp signals are also placed immediately in line with the pair of cords to which it belongs, so that either of these lamps lighting is a signal to pull out that particular pair of cords. In this way all the selection which the operator is called upon to perform is confined to executing the orders of the calling subscribers; *i. e.*, trunking out the order if the subscriber is not directly wired to the switchboard, or calling the subscriber if he is connected to the switchboard.

CHAPTER XVII.

LOADED TELEPHONE CIRCUITS.

It has long been known that an increase in the inductance of a telephone line increases its telephonic carrying capacity, or reduces its apparent impedance to telephonic currents. In a piece of apparatus such as an induction coil, relay, etc., the presence of inductance is almost wholly objectionable, and increases the impedance of the apparatus, so that the instrument with the same ohmic resistance, but with reduced inductance, would offer less obstruction to the waves of alternating currents carrying speech.

When, however, inductance is distributed along a telephone line, by spreading the two wires of a telephone circuit further apart, whereby the loop they form is increased in area, and the magnetic flux linked with that loop increased for a given current strength in the circuit, the impedance of the line is increased, as viewed from the sending end, for any given frequency of speech-wave alternation. The same alternating E. M. F. generated in the transmitting induction coil is, therefore, only enabled to send a feebler alternating current strength on to the line. The amount of power delivered to the line at the sending end is, however, practically the same, since the E. M. F. at induction-coil terminals automatically rises as the sending current is reduced. While, therefore, the power delivered to the line in speech alternating currents is nearly the

same, whether the line has much or little inductance, the power wasted along the line in heating the copper is considerably reduced when inductance is added to the circuit, since this waste of power increases with the square of the current strength. A high-inductance telephone line is, therefore, other things being equal, virtually a high-pressure telephone line, and just as increasing the pressure of transmission in electric lighting or power transmission decreases the loss of power in transit by decreasing the I^2R loss in the conductors, so the high-pressure telephone line decreases the loss of power, and enables the speech currents to be carried further before being practically extinguished.

Although efforts have been made for some time to increase distributed induct-

ance of overhead telephone lines by spreading the wires of the circuit as far apart as was reasonably possible, yet there is a limit to the amount of inductance which can be added in this manner, since the inductance does not increase in the same proportion as the separating distance. It has recently been found, however, that inductance could be inserted in blocks or lumps along the line, instead of being uniformly distributed, provided that the lumps were not inserted too infrequently. The expense of such loading or artificially added inductance increases with the number of loads which have to be employed, so that if, for example, a load had to be inserted at every pole along a telephone line, it is unlikely that loading would be a practically useful device, since it would, probably, be cheaper to use larger copper wires, and thus to reduce the waste of

energy in I^2R, by diminishing the resistance R, rather than by attempting to diminish the current strength I.

It is found, however, that overhead telephone lines may be successfully loaded with inductance coils inserted at intervals of about two or three miles, and that underground telephone cables may be successfully loaded with inductance coils at intervals of about one-half a mile. Such loading is clearly unnecessary on short telephone lines, seeing that their effective impedance viewed from the receiving end is necessarily comparatively small, but on very long lines, or on shorter lengths of underground line that may at some times form a part of a long-distance circuit, loading is valuable for reducing the virtual impedance of the line viewed from the receiving end, or allowing a greater current strength

to be received over the long-distance circuit. In this way it becomes possible markedly to extend the commercial limiting distance of telephonic transmission, by the use of a much smaller quantity of copper in the inductance coils at intervals, than would be necessary to distribute along the line wires, in order to reduce the total resistance of the circuit to the correspondingly effective degree.

When any succession of electric impulses is communicated to the sending end of a telephone circuit, the impulses are conveyed along the circuit in the form of a succession of electric waves. If the electric conditions at the sending end assume a steady state, as, for example, when an alternating E. M. F. of given frequency and magnitude is steadily impressed on the circuit, the transmitted

electric waves settle down into a steady state, in a period of time that is exceedingly brief. If we could examine the steady electric condition of the circuit along the line, with regard to alternating pressure and current, by means of a suitable alternating-current voltmeter and ammeter, we should find that the voltmeter indications, and likewise the ammeter indications, would periodically vary along the line, rising and falling in successive waves, but the indications of the instruments would be steady at any one place. If we imagine that an electric survey of the circuit were made during the continuance of the steady state with the constant frequency and magnitude of impressed E. M. F., we would find that the crests of the waves of pressure or of current repeated themselves at uniform intervals along the line. The distance between

the crests of these stationary waves might be called the semi-wave length. The wave length will be constant for any given frequency of impressed simple alternating E. M. F., although the positions of the crests may all shift one way or another, if the terminal impedances are varied. That is to say, the phase of the waves of current and pressure along the lines in the steady state will vary when the terminal conditions are varied, but the wave length is constant for one and the same frequency. The wave length depends upon the inductance per mile and capacity per mile.

The wave length of transmission is very nearly inversely proportional to the frequency of simple alternating current. That is to say, if the wave length be 10 miles, for a frequency of 100 cycles per

second, it will be 5 miles, for a frequency of 200 cycles per second, and so on. All of the energy of alternating currents is handed on from the generating to the receiving end through the medium of such waves. If, therefore, the line be loaded by the insertion of inductance coils at regular intervals, it is easy to understand that when these intervals are as great as a semi-wave length for the frequency of alternation considered, the effect of loads on the transmission may differ markedly from the effect of the same quantity of inductance distributed uniformly along the line. Thus a wave length of 10 miles represents two crests and two troughs in that distance, and a distance of 5 miles between adjacent crests. In the analogy of a vibrating string the nodes or stationary points will be 5 miles apart, and between them the ventral segments, or

belly-like segments of vibration, will also be 5 miles apart from centre to centre. If now the inductance loads should be inserted at intervals of 5 miles, they might happen to fall at or near the nodes, and the ventral segments of maximum vibrational activity would be devoid of added inductance; consequently, the effect of such added inductance could only be very imperfectly developed. In order to make sure that at least one inductance load shall fall within every ventral segment, or semi-wave length, it would be necessary to insert at least two loads to the semi-wave length, or four to the complete wave length, and it is found in fact that if there are four or more loads per wave length, the loaded inductance behaves in nearly the same beneficial manner as distributed inductance; whereas, if the loads are spaced fewer than four or three to the wave

length, the effect of the loads is adverse rather than beneficial to the transmission. As the frequency of alternation increases, the spacing of the loads, in order to preserve the same proportional wave distribution, must be correspondingly increased; so that with loads placed 2 miles apart we might expect that all wave lengths of, say, 8 miles or over, would be affected beneficially by the loads, while all wave lengths much below 8 miles, would either be not assisted by the loads, or actually interfered with. This would mean that all frequencies up to, say, the frequency having a wave length of 8 miles would be assisted telephonically, while higher frequencies would be interfered with.

In music, the frequencies which are directly produced with the aid of instru-

ments lie between the limits of about 40 and 4,000 cycles per second, and the fundamental vibrations of the human voice in speech or singing are contained within a much narrower range of about 100 to 1,000 cycles per second. Vocal sounds, however, of a given fundamental pitch, are accompanied by over-tones of much higher pitch, and the preservation of a certain amount of these higher pitched over-tones appears to be necessary in order to clearly distinguish the transmitted speech. It is at the present time uncertain just how high the frequencies lie that are essential to commercial telephony, but it would seem probable that, if the range between 100 and 2,500 periods per second can be commercially transmitted without serious selective absorption, the results are commercially. On this basis of assumption it becomes essential to provide about 4 loads per

wave length for a frequency of 2,500 periods per second, in which case all lower frequencies will be fully provided for. This means that all speech waves must encounter 10,000 loads per second in their transmission along the electric circuit.

The loads for overhead wires have thus far consisted of induction coils, the two windings of which are similar, symmetrical, and carefully insulated from each other, one winding being inserted in one wire and the other winding in the opposite or return wire. This induction-coil method of loading is superior to simple inductance-coil loading, since it not only maintains the electric balance and symmetry of the circuit, but also reduces the amount of copper necessary for a given extra resistance of the circuit, by employing the E. M. F. of the current in one

line to force the flux through the loops of the other line, as well as its own line. In other words, the effective inductance is thereby increased. It seems likely, however, that in the future the loads will be reduced in size, and in the amount of copper they contain, by employing a very finely divided iron core. The iron core has the advantage of greatly increasing the inductance for a given number of turns, but has the disadvantage of introducing some slight loss of power by eddy currents in the core. To reduce this loss as far as possible, the diameter of the wire is made as small as is commercially possible. The inductance coils are enclosed in a cast-iron shell to protect them.

Similar inductance loads are introduced into underground telephone cables, but owing to the fact that these cables have a

greater electrostatic capacity per mile than overhead wires, the inductance loads have to be introduced at shorter distances and the loading is heavier than with overhead wires. Fig. 152, represents diagrammati-

FIG. 152.—DIAGRAM OF LOADED TELEPHONE LINE.

cally a loaded telephone circuit, with a transmitter at *A*, and a receiver at *B*, each connected with the circuit by an induction coil *c*, having its fine-wire coil in the line. Induction coils *a a'*, *b b'*, *c c'*, are inserted at regular intervals along the line, the two windings of each induction coil being similar, symmetrical, mutually assisting, but carefully insulated.

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